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MICROSTRAINING AND DISINFECTION OF COMBINED SEWER OVERFLOWS. PHASE II

Michael B. Maher

Crane Company

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16. ABSTRACT: A microstrainer reduced the SS of the combined sewer overflow from 50 to 300 mg/1 to 40 to 60 mg/1 operating at an average rate of 38.4 m/hr (16 gpm/sq.ft.) Addition of polyelectrolyte improved the overall performance of the microstrainer. The effluent SS was reduced to an average of 23 mg/1 and the flow rate increased to an average of 87.5 m/hr. (36 gpm/sq.ft.) The combined sewer served a residential area in Philadelphia composed of 4.5 hectares (11.2 acres). The average dry weather flow was 91 cu m/day (24,000 gpd). An extensive coagulation study revealed that cationic polyelectrolytes were most suitable for this particular application. The concentrations applied ranged from 0.25 to 1.5 mg/1. Coliform reductions across the microstrainer were observed. It was also found that microstrained effluent could be more easily disinfected than raw combined sewer overflow. Chlorine and ozone were used for disinfection at low contact times. The capital cost of a microstrainer installation followed by high rate chlorine contact chamber is reported as $60660/hectare ($24480/acre). When polyelectrolyte addition equipment is included, capital cost is $37250/hectare ($15030/acre). Costs are in 1973 dollars.

This report, submitted in fulfillment of Project S-800966 (formerly 11023 FWT), is a continuation of the work previously reported in EPA Reports 11023 EVO 06/70 and 11023 FWT 01/73.

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MICROSTRAINING AND DISINFECTION OF COMBINED SEWER OVERFLOWS - PHASE III

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The pollution problems associated with combined sewer overflows have been inherited by our cities because of lack of foresight and have grown enormously in the past thirty years. Huge volumes of untreated sewage and runoff contaminate our streams and estuaries after each heavy rainfall. One of the most economical solutions to this problem is the utilization of a microstrainer followed by high rate disinfection. The results of a pilot plant microstrainer with high rate disinfection using both ozone and chlorine are reported herein. This microstrainer was located at a combined sewer overflow outfall in Philadelphia and was operated with and without polyelectrolyte addition.

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ABSTRACT

A microstrainer with a stainless steel screen having openings of 23 microns reduced the suspended solids (SS) of the combined sewer overflow from 50 to 300 mg/l to 40 to 60 mg/l operating at an average rate* of 38.4 m/hr (16 gpm/sq ft). The addition of polyelectrolyte improved the overall performance of the microstrainer. The effluent SS was reduced to an average of 23 mg/l and the flow rates increased to an average of 87.5 m/hr (36 gpm/sq ft).

The combined sewer served a residential area in Philadelphia comprised of 4.5 hectares (11.2 acres). The average dry weather flow was 91 cu m/day (24000 gpd). The average overflow rates encountered were about 70 times the average dry weather flow.

An extensive coagulation study revealed that moderately charged, high molecular weight, cationic polyelectrolytes were the most suitable for this particular application. The concentrations applied ranged from 0.25 to 1.5 mg/l.

Coliform reductions across the microstrainer were observed. It was also found that microstrained effluent could be more easily disinfected than the raw combined sewer overflow. Chlorine and ozone were used for disinfection at low contact times.

The capital cost of a microstrainer installation (based on 8.2 cu m/min hectare (1.96 cfs/acre) followed by a high rate chlorine contact chamber is reported as $60660/hectare ($24480/acre). When polyelectrolyte addition equipment is included, the capital cost is $37250/hectare ($15030/acre). Costs are in 1973 dollars.

This report, submitted in fullfillment of Project S-800966 (formerly 11023 FWT) is a continuation of the work previously reported in EPA Reports 11023 EVO 06/70 and 11023 FWT 01/73.

* Based on the flow through the submerged screen area.

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* Presently with Cyrus Rice, Division of NUS.

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PREAMBLE

This project was extended into Phase III to confirm the performance of the microstrainer on combined sewer overflow from Phases I and II, to obtain more high rate disinfection data using both ozone and chlorine and to operate the microstrainer with coagulant addition.

In Phases I and II, the SS removal percentages were found to be higher for higher influent SS concentrations. The lower influent SS concentrations tended to produce somewhat lower effluent SS concentrations but eventually approached a plateau. Therefore, it was proposed that the program be extended to determine if coagulant addition could be applied to reduce the residual SS problem. It was also believed that the use of polymeric materials would permit higher throughput rates due to agglomeration and enlargement of the influent particulates.

Phase III was conducted basically in three parts: (1) The pilot microstrainer and disinfection equipment were operated as in Phase II; (2) a coagulation study was undertaken to determine the most suitable coagulants; and (3)the microstrainer and disinfection equipment were operated as in part (1) but with coagulant addition.

SECTION I

CONCLUSIONS

1. Suspended solids (SS) removal performance tends to confirm previous work (1) (2). Influent SS in the combined sewer overflow were reduced from 50-300 mg/l to 40-60 mg/l. The average SS removal in Phase III was 70%. The microstrainer operated at an average flow rate of 38.4 m/hr (16 gpm/sq ft). The flow rates of 85.9 to 110.0 m/hr (35-45 gpm/sq ft) reported in Phase II were never achieved in the Phase III study.

2. Polyelectrolyte addition improved the operating efficiency of the microstrainer. SS removal increased to 78% and the average effluent SS was reduced to 23 mg/l. The flow rate was also increased to an average of 87.5 m/hr (36 gpm/sq ft).

3. After an extensive laboratory coagulation study, moderately charged, high molecular weight cationic polyelectrolytes were found to be the most suitable for this application. Betz 1150 and Atlasep 105C were used in this study at initial concentrations ranging from 0.25 to 1.5 mg/l.

4. A particle size analysis on the backwash showed that the average size particle retained by the screen was 9.5 microns with polyelectrolyte addition and 3.9 microns without polyelectrolyte addition. It was also found that the microstrainer removed particles as small as 0.07 microns. The ratio of screen size to smallest particle size removed was 330 to 1.

5. The total coliform content of the combined sewer overflow varied from 3×10^4 to 5×10^6 cells/100 ml. The fecal coliform content also varied from 3×10^2 to 6×10^4 cells/100 ml. The microstrainer demonstrated

the ability to remove an average of 77% total coliforms and 76% fecal coliforms.

6. The microstrainer reduced the organic material in the combined sewer overflow. With polyelectrolyte addition, the volatile suspended solids (VSS) were reduced by 79%, total organic carbon (TOC) by 52% and chemical oxygen demand (COD) by 57%. When no coagulant was added, the VSS were reduced by 68%, TOC by 32% and COD by 37%.

7. The percent VSS/SS ranged from 30-55% which is much lower than the normal percent VSS/SS usually encountered in sewage treatment plant influents (60-85%) and was indicative of the contribution of inorganics in storm runoff.

8. The microstrainer operated at a waste rate of approximately 3% of the influent flow with a SS concentrarion of about 700 to 1000 mg/l.

9. The microstrainer reduced the total phosphates by 15% without polyelectrolyte addition and by 24% with polyelectrolyte addition.

10. Disinfection of microstrained effluent to below 200 fecal coliforms/100 ml was performed using short contact times (3 minutes) with initial chlorine concentrations at as low as 2.6 mg/l and initial ozone concentrations at as low as 3.8 mg/l. The untreated combined sewer overflow was also successfully treated with chlorine to below 200 fecal coliforms/100 ml at an initial concentration as low as 5 mg/l with 4 minutes of contact time. It was evident during this study that with microstraining adequate disinfection could be accomplished at much lower chlorine concentrations than the concentrations required for the raw combined sewer overflow.

11. The design criteria used for the construction of the special, high mixing intensity, pilot size contact chambers, appear to be appropriate and practicable for full size units.

12. The special character of solids in combined sewer overflow (and stormwater) is vastly different from other municipal and industrial wastewaters and from the potable water sources to which a microstrainer is normally applied. The high level (liquid) differentials across the screen required to achieve the high flow rates necessary to be practicable in stormwater service are far beyond those conventionally used. Thus, empirical relations and experience useful in conventional applications are misleading in the microstraining of combined sewer overflows.

13. The capital cost of a microstrainer followed by high rate chlorination would be $60660/hectare ($24480/acre) in 1973 dollars. The operating costs would be $0.012/cu m($0.046/1000 gal). These costs do not include engineering or land costs. The capital costs for the microstrainer with polyelectrolyte addition at 1 mg/l decrease to $37250/hectare ($15030/acre) since only half as many microstrainer units are necessary. The operating costs would be $0.012/cu m ($0.045/1000 gal). Even with the additional costs for polyelectrolyte addition, the microstrainer with high rate chlorination is still practical and remains to be the least expensive of the alternative methods considered (1), except for surface impounding when inexpensive land is available. All costs were based on an overflow of 8.2 cu m/min hectare (1.96 cfs/acre).

SECTION II

RECOMMENDATIONS

1. Microstrainers employed in storm flow service may be operated at high differentials of about 61 cm (24 inches) of water. At this differential and with similar solids loadings as encountered in this study, flows of 36.0 to 60.0 m/hr (15-25 gpm/sq ft) can be obtained with an effluent quality of 40 mg/l suspended solids. With polyelectrolyte addition, performance can be improved to obtain a throughput of 75.5 to 95.4 m/hr (30-40 gpm/sq ft) with an effluent quality of 20 mg/l.

2. A full scale microstrainer with polyelectrolyte and high rate chlorine treatment should be built and operated for storm flow to demonstrate improved stream quality.

3. Polyelectrolyte evaluation should be monitored on additional storms to extablish guidelines for mixing intensities, contact times and maximum and minimum concentrations with a broader range of suspended solids concentrations in the combined sewer overflow.

4. The influence of mixing intensity for disinfection of wastewater should be recognized since a sizable savings in capital cost may be realized with the substantial decrease in contact time.

5. Because of the peak instantaneous capacity limitation of the equipment, the benefit of flow equalization especially within the sewers themselves should be evaluated prior to an actual design.

6. Based on the results (for this application), the disinfection equipment should be designed to be capable of providing a maximum initial concentration of 6 mg/l of chlorine and 9 mg/l of ozone if necessary.

7. More disinfection data should be collected on additional storms to continue to evaluate disinfection concentrations to meet low level coliform counts and to determine the adequacy of contact times as short as 1.25 minutes.

8. Although it appeared from the jar tests and in the pilot plant facility that adequate mixing and contact time had been provided for flocculation, more research should be undertaken to optimize these parameters.

9. For an actual microstrainer design, provisions should be made to install polyelectrolyte equipment but care should be taken to provide proper dilution, injection, and mixing of the polyelectrolytes. When the feed to the microstrainers is pumped, the polyelectrolyte should be added to the pump suction, where possible, to take advantage of the turbulent mixing provided.

10. Observations have indicated the benefit of increasing the percent suspended solids removal by increasing the polymer concentration; however, the balance between increased polymer addition vs. efficiency and throughput should be considered in operation of future facilities. Care should also be taken to prevent polyelectrolyte overfeeding which would foul the screen.

11. Handling methods of the microstrainer waste stream should be investigated. The obvious solution would be to discharge the waste stream to the interceptor during microstrainer operation. However, if the interceptor cannot accept this flow, this volume may have to be stored and later slowly discharged to the interceptor when it is less taxed.

12. It has been proposed that the microstrainer can be utilized as a tertiary treatment step for a nearby treatment plant when not in storm service. (3)

SECTION III

INTRODUCTION

PREVIOUS WORK

The original work covered the periods of January, 1969 through September, 1969 and June, 1971 through February, 1972 and was reported as EPA "Water Pollution Control Research Series", Reports 11023 EVO 06/70 and 11023 FWT 01/73.

The previous work was performed at the same 4.5 hectare (11.2 acre) drainage area served by a combined sewer in a residential area of Philadelphia, Pa. A Crane-Glenfield microstrainer was fitted first with 4.4 sq. m (47 sq ft) Mark "I" (35 micron openings) screen and later with Mark "O" (23 micron) screen. The SS content of the storm overflow of the first two phases ranged from 20 to 700 mg/l. The flow rate through the microstrainer ranged from 2.4 m/hr (1.0 gpm/sq ft) to 110.2 m/hr. (45.0 gpm/sq ft).In the latter part of Phase I, the Mark"I" screen was replaced with Mark "O" screen and 4/5 of the screen area was masked with plastic sheeting so that higher velocities could be attained. The outlet weir level was set initially for a 15.2 cm (6 in) maximum differential but was later changed to 61.0 cm (24 in) in Phase I.

The SS removal ranged from 20 to 99+% removal with the higher removals generally occurring at the higher influent SS levels. Coliform removal by the microstrainer were observed; however, the results were not consistent. Organic removals as measured by TOC and COD ranged from 25 to 40%.

Disinfection using chlorine was employed on both the influent and effluent of the microstrainer. In Phase I bench scale chlorination studies indicated that disinfection could be accomplished in short contact periods with high velocity

gradients. In Phase II, the high rate chlorine chambers were installed to treat both the raw combined sewer overflow and the microstrainer effluent. With chlorine contact times of only two minutes and initial concentrations as low as 5 mg/l of chlorine, total and fecal coliforms were reduced from 10^6 cells/100 ml and 10^5 cells/100 ml levels to under 10 cells/100 ml. Ozonation of the microstrainer effluent was also performed in cocurrent - countercurrent columns and four orders of magnitude bacterial kill was obtained with an initial concentration as low as 4 mg/l and a 12 minute contact time.

An economic study showed that microstraining with high rate chlorine disinfection with high turbulent mixing was the least expensive and the most compact of the other methods. The other methods included screening, flotation, Bio-Disc, activated carbon, primary clarification, separate sewers, activated sludge and surface and sub-surface impoundments.

PRESENT WORK

The third phase of the work was conducted to confirm the performance of the microstrainer and the disinfection results. Also, it was believed that the use of coagulants would reduce the effluent solids level as well as increasing throughput rates so provisions were made to add coagulant to the microstrainer influent.

While the microstrainer operated without coagulant addition, a laboratory coagulant survey was conducted to determine the most suitable coagulants for this installation. The coagulants which exhibited the best characteristics were then used on a bench scale microstrainer before testing them on the full scale pilot facility.

Disinfection of the raw combined sewer overflow and microstrainer effluent was performed in the two high rate chlorine contact chambers which had been installed in Phase II.

Ozone was also used to disinfect the microstrainer effluent and was introduced with equipment borrowed from the Philadelphia Water Department. The disinfection equipment was automated so that samples could be taken even if the installation was unmanned during a storm event.

Project time and infrequency of rainfall permitted only eight storm events where polyelectrolyte addition could be evaluated; however, twenty-one storms were encountered when the microstrainer operated without coagulant addition.

SECTION IV
EXPERIMENTAL EQUIPMENT

Microstrainer

The Microstrainer is a rotating drum filter. The type used in this study was 1.68 m (5 ft) in diameter and 0.92 m (3 ft) long and was covered by specially woven Mark "0" stainless steel wire fabric having nominal openings of 23 microns. 80% of the screen area was blanked with three layers of polyethylene sheets so that the effective area was 0.87 sq m (9.4 sq ft).

The water entered the drum through the open end and flowed radially through the drum into the outlet chamber depositing SS on the inside of the drum screen. (Fig. 1). The drum rotated continuously and passed the fouled screen under the backwash jets which washed the solid material into a hopper and then to waste. The deposited solids formed a mat which become a much finer filter than the screen itself and caused a resistance which increased the liquid level differential between the influent and effluent chambers. As the differential increased, the automatic speed controller increased the drum speed from 2 rpm at idle to 6.8 rpm at 61 cm (24 in) differential. The preferred mode of operation for this application was to maintain a differential of 61 cm by use of the reset-proportional band control. This gave an effective submerged screen area of 0.72 sq m (7.8 sq ft).

The microstrainer ran at an idle speed of 2 rpm continuously under an ultraviolet light. The ultraviolet light prevented the formation of bacterial and other organic slimes which would tend to clog the screen. City water was used for backwash. At the onset of a storm when the overflow height above the weir in the trough below the outfall reached 3 cm (0.1 ft), an automatic level control started the disinfection equipment, the automatic sampler controls and the feed pumps in the trough,(Fig. 2).

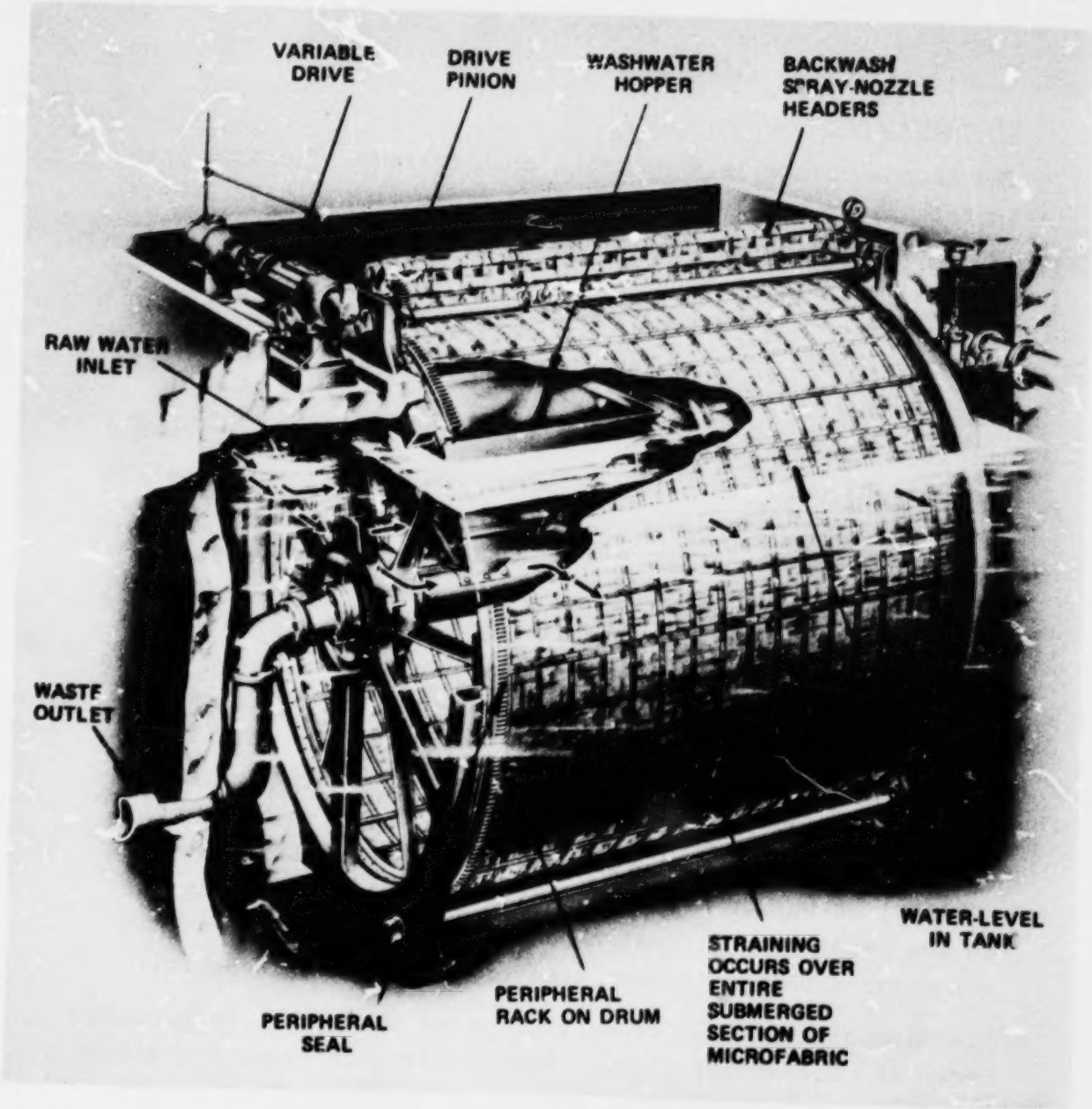

Figure 1

Isometric Drawing of a Microstrainer

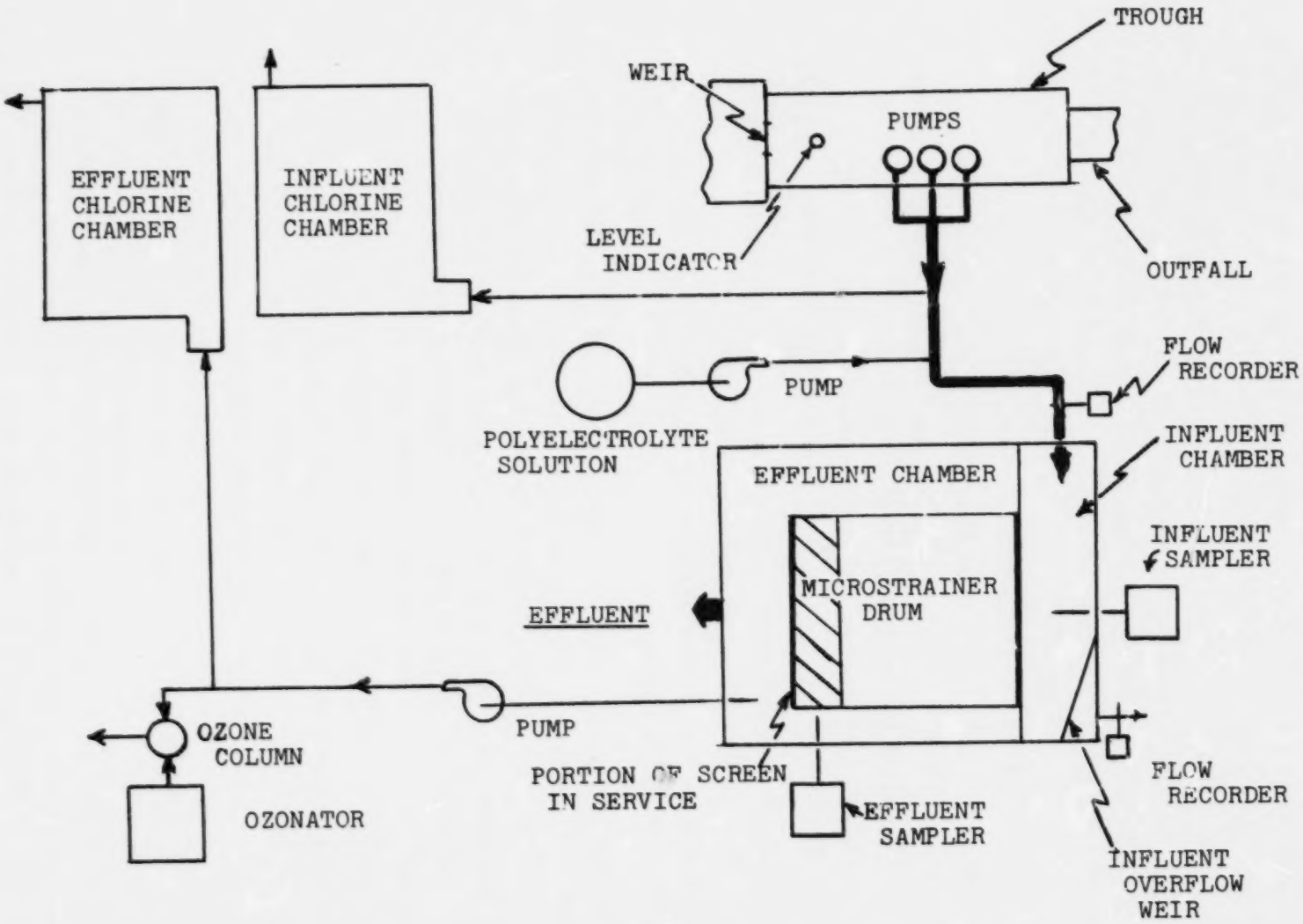

Figure 2
Schematic Diagram of Microstrainer and Disinfection Systems

The flow rate of combined sewer overflow to the microstrainer was controlled at a constant rate, predetermined by the selection of the number of pumps to be activated by the storm overflow level control. The flow rate through the microstrainer was then independent of the combined sewer overflow rate and was determined by the pump rate minus the flow over the overflow weir in the influent chamber.

Chlorine Disinfection Equipment

The clorine disinfection equipment consisted of two specially designed chlorine contact chambers each equipped with a Shutte and Koerting, variable area, rate of flow meter for the inflow measurement; a Lapp, variable capacity, hypochlorite metering pump; and a container of sodium hypochlorite solution.

The equipment was automatically operated at the onset of the storm. Microstrained effluent was pumped to one of the chambers while the other chamber was fed by a tap off the microstrainer inlet line.

The contact chamber shown in Fig. 3 provided 4.25 minutes of contact time at a flow rate of 41.5 cu m/hr (20 gpm). The large number of baffles insured true plug flow so that full residence time was utilized for chlorine contact. The high liquid velocity of 0.82 m/sec (2.7 ft/sec) together with the corrugated baffles resulted in a head loss of 3.7 cm (1.5 in) over 14.5 meters (64 ft) of liquid travel.

Sample taps were located at 1/4, 1/2, 3/4 of the total length of the chamber and at the outlet which provided samples at 1.25, 2.25, 3.25 and 4.25 minutes contact time (Fig. 4). Solenoid valves connected to timers were installed at corresponding taps 1, 3, and 4 on the effluent and tap 4 on the influent so that disinfection samples could be obtained automatically after 15 minutes of operation. These samples, for bacteria analysis, were collected in sterile bottles containing several milliliters of sodium thiosulfate solution to

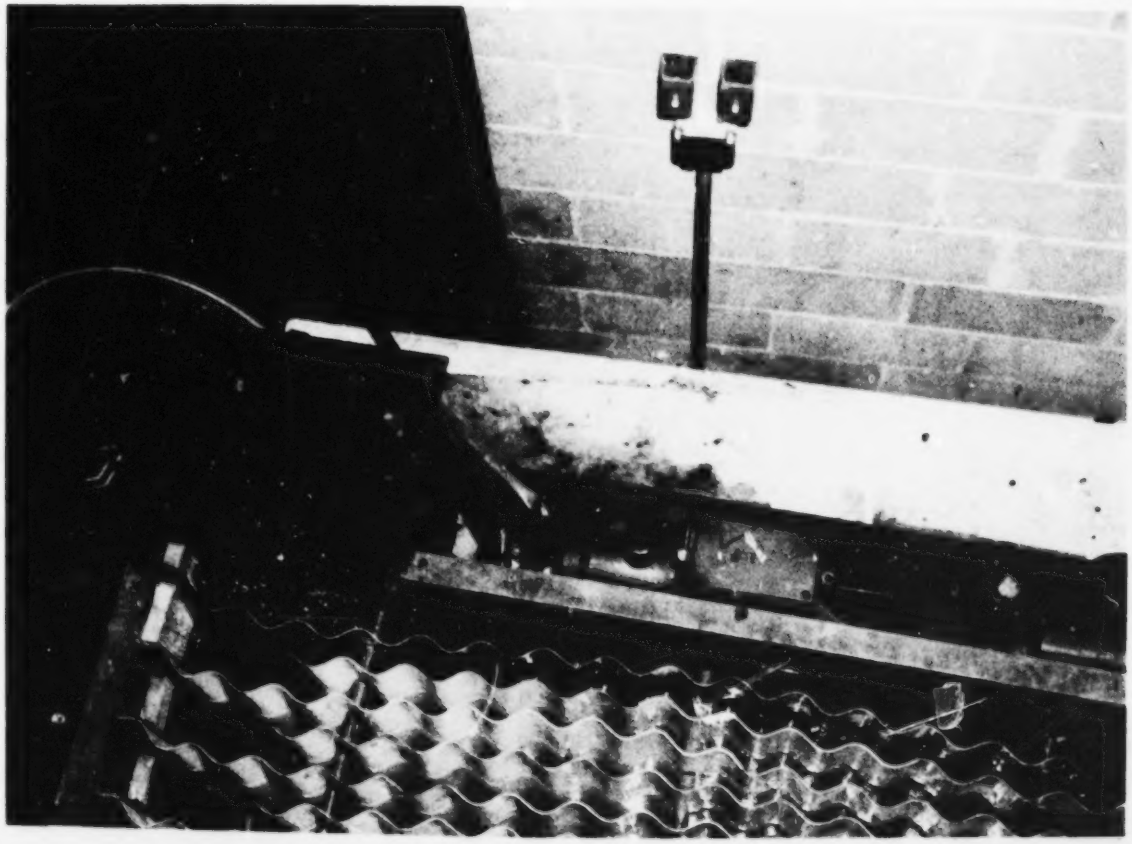

Figure 3
Top View of Chlorination Chamber

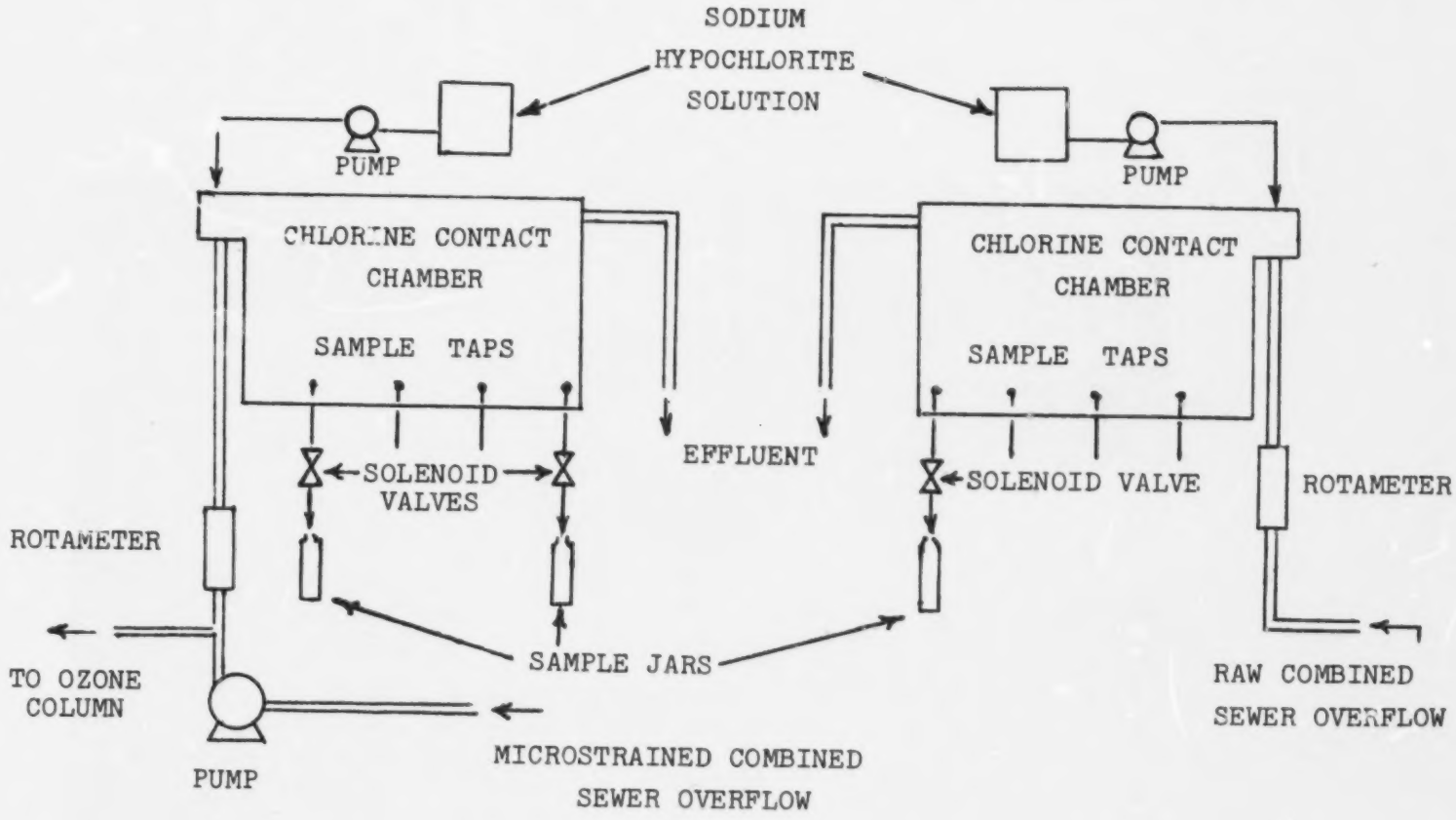

Figure 4

Schematic Diagram of Chlorination Equipment

quench the chlorine and were shaken vigorously, covered and refrigerated.

All disinfections were performed at a constant flow rate of 41.5 cu m/hr (20 gpm). Both the raw combined overflow and the microstrainer effluent were treated simultaneously during storm flow operation. A pre-selected chlorine concentration was controlled by the setting of a positive displacement (Lapp) pump and by the initial concentration of the hypochlorite solution.

The chlorine solution concentrations were determined according to the iodometric method in STANDARD METHODS (4). Chlorine residuals were measured with the orthotolidine comparator set. The samples were measured after collection. With the short reaction time between the sample and the orthotolidine reagent, the STANDARD METHODS (4) procedure indicates that for practical purposes only free chlorine is measured.

Ozone Disinfection Equipment

A tube-type laboratory ozonator and a 3 m by 8.25 cm (10 ft x 3.25 in) plexiglass cocurrent contact column (Fig. 5) were borrowed from the Philadelphia Water Dept. to perform the ozone disinfection study on the microstrained effluent for Phase III. This set-up was chosen over the existing Trailigaz plate ozonator with cocurrent-countercurrent columns which had been used in Phases I and II, because it reached steady state much faster (5 minutes as opposed to 30-60 minutes). Also with the electrical facilities available, the system could be automated more easily.

Microstrained effluent was introduced to the cocurrent column via a nozzle pointed down onto the porous stone diffuser. This produced high turbulence and also supplied the highest concentration of ozone to the incoming wastewater. The column operated at 85-95 percent ozone absorption, with a contact time of 3.3 minutes.

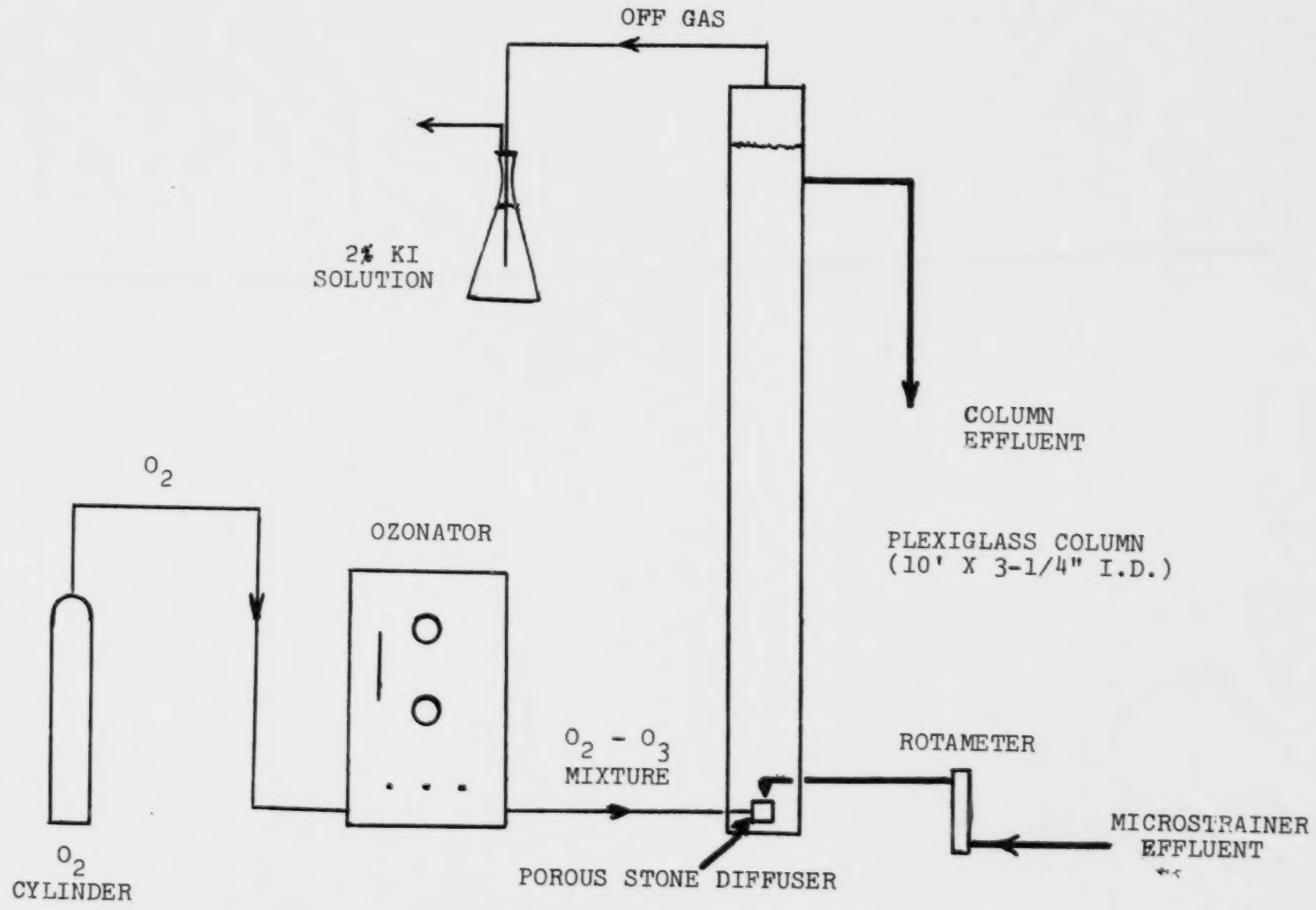

Figure 5
Schematic Diagram of Ozonation Equipment

The initial ozone concentration was varied from 3.1 to 8.4 mg/l and was dependent on the ozonator voltage, the gas flow rate, the wastewater flow rate, and the percent absorption. The concentration of the incoming gas and the off gas were determined by the iodometric method in STANDARD METHODS (4).

As in the chlorination set-up a sample of the ozonated effluent was taken after 15 minutes of operation for bacterial analysis. Sodium thiosulfate was also used to quench any ozone residual although no residual was ever found using the orthotolidine method from STANDARD METHODS (4).

Polyelectrolyte Addition Equipment

The polyelectrolyte solutions were prepared every week at 0.15% in a 135 liter (36 gal) plastic container. A Wallace & Tiernan positive displacement pump was used to inject the solution to about 0.04% before entering the microstrainer influent line (Fig. 2).

A Reynolds number of 1.6×10^5 was calculated for the microstrainer influent line showing turbulent conditions. The polyelectrolyte was added 4.9 meters (16 ft) prior to combined sewer overflow discharge point and had a retention time of 4.7 seconds. The pipe had four right angle bends between the point of polyelectrolyte addition and the point of discharge into the inlet chamber. The combined sewer overflow entered the influent chamber to the microstrainer drum and had a detention time of about 3.6 minutes (At maximum flow, there was no overflow over the influent overflow weir.)

Unfortunately, the degree of mixing achieved was dependent on the geometry of the system available and could not be varied; however, visual observations of influent samples taken at the opening of the drum showed coagulated particles in suspension indicating good mixing in the chamber.

It should be noted that for this installation the polyelectrolyte mixing occurred in the pipe line, in the influent chamber and inside the portion of the microstrainer drum which was blocked off. In an actual installation where the microstrainer is gravity fed, it would be sized for full screen utilization; therefore, a suitable mixing and flocculation chamber may have to be provided to insure good coagulation. The polyelectrolyte would be fed after the bar screens and would be mixed and detained in a baffled chamber. The rate of coagulant addition would vary with flow and would be injected by a variable speed positive displacement pump which would be controlled by a signal from a measuring device such as a flume. In a full size unit where the microstrainer is pump fed, it would be advantageous to add the polyelectrolyte directly to the pump suction to take advantage of the turbulent mixing in the pump. It was impractical at the pilot plant facility to add the polyelectrolyte to the pump suction because of the geometry of the pilot plant site; however, this would have been the preferred mode of operation.

SECTION V

SAMPLING

Sample bottles were washed with soap and water, rinsed with methanol and thoroughly dried with hot air. After each storm, the sampler tubes were flushed with hypochlorite followed by a high velocity rinse with city water. The bottles were then placed in the automatic vacuum samplers (Fig. 6). The samplers each held 24 evacuated bottles and once the reset timers activated the units, took samples every two minutes. The influent reset timer was set for two minutes to give sufficient volume of combined sewer overflow in the influent chamber before sampling was initiated.

At first, the influent sample was withdrawn through a 2.54 cm I.D. pipe (1.0 in) located 5.1 cm (2 in) axially out from the inlet end of the drum and about 46 cm (18 in) radially to the emerging side of the drum center. The sample flow then went through a valve to the 24.7 liter (6.5 gallon) flowthrough sample chamber.

Because of the low influent suspended solids results obtained for July 11 and 15, 1973, the sampler equipment was inspected and a clogged valve was discovered. As a result, the influent sampler inlet housing was placed directly in the influent chamber in approximately the same position as the former sample inlet pipe. The effluent sample inlet line was located in the center of the open screen panel about 5 cm (2 in) from the floor and 5 cm (2 in) from the screen and discharged to the 19 liter (5 gallon) effluent sample chamber which contained the sampler housing. The flow through the sampler chamber was about 19 liters/min (5 gpm).

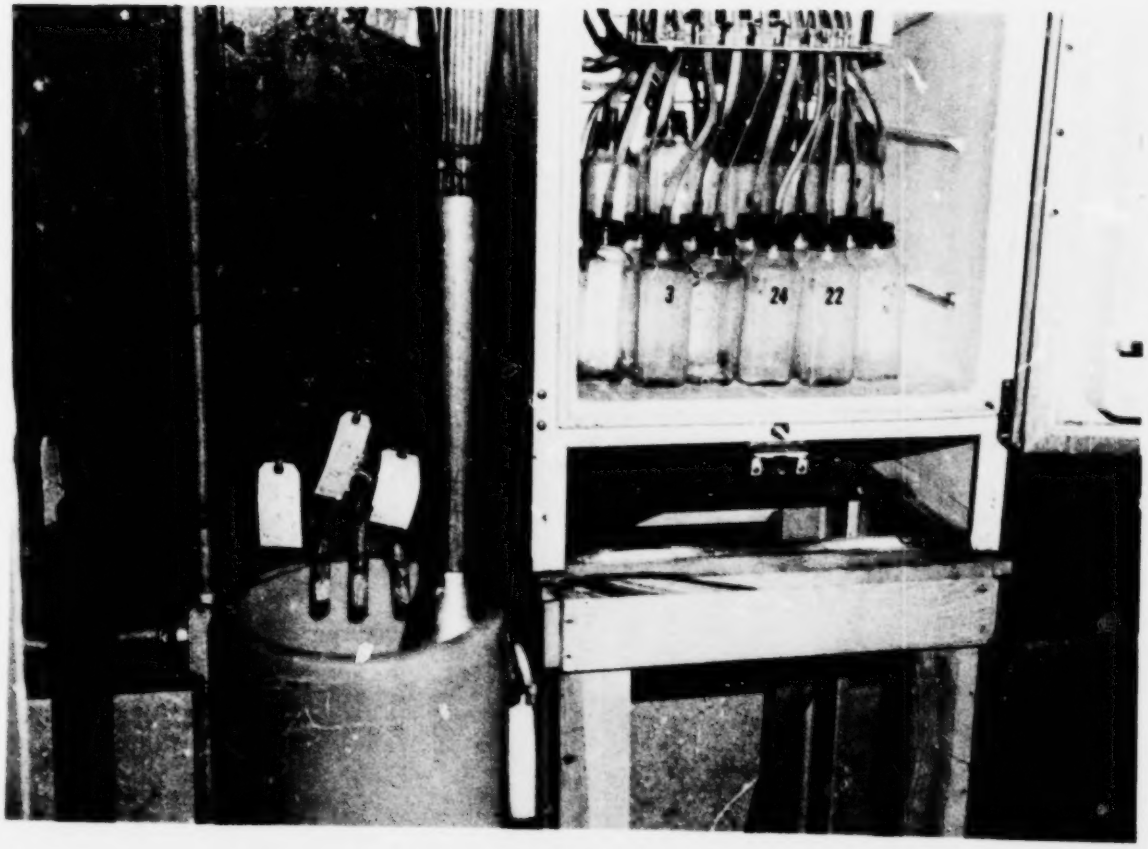

Figure 6
Sampler with Flow Through Chamber

Once the reset timers timed out, the samplers collected discrete samples of approximately 300 ml each of the two flows every two minutes for the duration of the storm and stored them in refrigerated chambers. The samples were then composited and sent to the Philadelphia Water Dept. laboratory for analysis. The analyses are given in Table 1. On three occasions effluent samples were composited in groups over different periods of the storm.

The storm flow conditions of January 3, 30 and 31, 1974 were synthesized by opening fire hydrants on the street so that more data could be obtained for polyelectrolyte addition.

Table 1. LABORATORY ANALYSIS

Date	Start-up	Sample	pH	Cond. (mmhos)	SS (mg/l)	VSS (mg/l)
4/26/73	6:35 PM	INF	6.7	39	22	11
		EFF	6.9	81	9	8
4/27/73	12:05 PM	INF	6.7	63	291	84
		EFF	6.9	160	89	26
5/3/73	3:00 PM	INF	7.2	147	260	64
		EFF	7.1	237	50	22
5/9/73	4:00 PM	INF	6.9	60	176	52
		EFF	7.1	128	48	6
5/17/73[k]	8:00 PM	INF	6.7	140	72	48
		EFF	7.0	140	50	40
5/20/73	12:00 N	INF	6.9	62	132	71
		EFF	6.9	89	54	27
5/27/73	12:15 AM	INF	6.9	134	155	48
		EFF	7.0	181	28	13
	9:50 AM	INF	7.1	128	97	36
		EFF	7.1	147	38	14
	2:45 PM	INF	6.9	119	70	41
		EFF	7.1	272	77	9
5/28/73	7:15 AM	INF	7.2	45	174	40
		EFF	7.2	64	58	14
6/22/73	8:25 PM	INF	7.5	420[v]	256	111
		EFF	8.0	527[v]	39	20
	12:00 N	INF	6.9	108[v]	293	123
		EFF	7.0	67[v]	48	15
	12:30 PM	INF	6.9	520	238	101
		EFF	6.9	710	47	17

Table 1 (continued). LABORATORY ANALYSIS

T-PO_4 (mg/l)	COD (mg/l)	TOC (mg/l)	TC/100 ml	FC/100 ml
3.6	33	9	5.0×10^5	$< 1.0 \times 10^4$
2.1	29	7	$< 1.0 \times 10^4$[a]	$< 1.0 \times 10^4$
3.2	190	55	6.8×10^5	1.8×10^4
1.4	142	34	$< 1.0 \times 10^3$[e]	$< 1.0 \times 10^2$
4.1	171	32	12.0×10^4[c]	3.0×10^2[d]
4.8	127	28	1.0×10^3	1.0×10^2[f]
3.0	119	26	11.0×10^5[g]	2.3×10^4
1.8	95	20	46.0×10^3	4.8×10^2
3.3	124	34	34.0×10^4	38.0×10^2
2.6	88	26	25.0×10^4	27.0×10^2
4.8	181	46	$< 8.0 \times 10^5$[i]	6.7×10^3[j]
4.8	169	38	$< 8.0 \times 10^5$[i]	1.7×10^4[j]
4.3	108	28	30.0×10^3[m]	7.3×10^4[n]
3.7	84	26	21.0×10^2[f]	5.8×10^4
3.8	100	22	20.0×10^4	5.0×10^4[o]
3.2	60	14	22.0×10^2	5.4×10^4
4.9	116	29	7.0×10^4[p]	47.0×10^4
3.1	88	21	26.0×10^2	8.4×10^4[q]
3.0	5920[l]	1600[l]	9.0×10^4[r]	$< 1.0 \times 10^4$[t]
2.2	96	24	9.0×10^2[s]	7.0×10^2[u]
5.0	284	104	53.0×10^5	$< 60.0 \times 10^3$
4.3	220	87	19.0×10^4	9.0×10^3
5.6	224	64	41.0×10^5	2.0×10^4
4.0	64	21	13.0×10^5	27.0×10^2
2.6	196	45	35.0×10^5	46.0×10^3
2.5	48	17	55.0×10^4	1.0×10^4

Table 1 (continued). LABORATORY ANALYSIS

Date	Start-up	Sample	pH	Cond. (mmhos)	SS (mg/l)	VSS (mg/l)
6/29/73	5:00 AM	INF	6.8	96[v]	92	17
		EFF	6.9	54[v]	47	8
	2:30 PM	INF	6.4	48[v]	113	29
		EFF	6.5	49[v]	56	15
7/11/73	3:00 PM	INF	7.2	130[v]	54	16
		EFF	7.3	61[v]	39	17
7/15/73	3:00 PM	INF	6.7	279[w]	23[x]	8
		EFF	7.0	79[w]	19	9
8/1/73	6:30 PM	INF	7.2	81	154	54
		EFF	7.0	148	63	26
8/2/73	4:30 PM	INF	7.1	65	78	32
		EFF	7.0	76	26	12
10/2/73	5:00 PM	INF	6.0	44	53	40
		EFF	6.5	65	19	14
11/28/73	3:00 PM	INF	6.9	111	204	101
		EFF-1	6.8	176	68	41
		EFF-2	6.8	159	30	19
12/5/73	11:00 PM	INF	7.3	160	108	54
		EFF	7.5	210	38	8
	8:00 PM	INF	6.7	47	171	150
		EFF	7.0	130	36	30
12/13/73	10:45 PM	INF	7.2	42	84	39
		EFF	7.4	73	5	4
12/20/73	10:55 PM	INF	7.5	103	65	18
		EFF	7.4	74	15	0
12/26/73	6:45 PM	INF	6.8	NR	86	52
		EFF	6.8	NR	28	20

Table 1. (continued) LABORATORY ANALYSIS

T-PO_4 (mg/l)	COD (mg/l)	TOC (mg/l)	TC/100 ml	FC/100 ml
2.0	57	22	16.0×10^5	14.0×10^3
1.6	57	19	59.0×10^4	74.0×10^2
2.4	64	30	18.0×10^4	71.0×10^2
2.9	52	18	64.0×10^4	51.0×10^3
1.5	4	15	89.0×10^4	15.0×10^4
2.5	0	15	14.0×10^4	15.0×10^2
0.6	42	12	62.0×10^3	5.0×10^3
1.6	38	15	60.0×10^3	6.0×10^3
4.0	125	39	45.0×10^4	32.0×10^3
4.4	87	26	50.0×10^4	7.0×10^3
2.2	64	22	26.0×10^5	18.0×10^3
1.8	16	16	15.0×10^5	7.0×10^3
1.3	88	31	NR	NR
0.75	48	18	NR	NR
2.59	326	71	NR	NR
1.51	65	18.5	NR	NR
0.61	245	22.5	NR	NR
3.0	91	38	NR	NR
1.35	61	26	NR	NR
2.77	NR	45	NR	NR
2.33	NR	22	NR	NR
2.21	92	32	9.7×10^5	5.0×10^5
1.3	64	21	9.0×10^3	1.3×10^3
3.0	296	67	1.3×10^6	6.0×10^5
2.9	75	27	4.0×10^5	8.0×10^4
0.88	1600	28	8.0×10^5	2.0×10^4
0.66	800	17.6	NR	NR

Table 1. (continued) LABORATORY ANALYSIS

Date	Start-up	Sample	pH	Cond. (mmhos)	SS (mg/l)	VSS (mg/l)
1/3/74	10:30 AM	INF	7.5	200	68	26
		EFF-1	7.2	220	45	12
		EFF-2	7.3	215	56	10
1/30/74	11:00 AM	INF	7.4	250	72	31
		EFF	7.6	275	4	4
1/31/74	11:00 AM	INF-1	7.6	275	44	20
		INF-2	7.4	269	53	21
		INF-3	7.4	269	69	21
		EFF-1	7.6	272	10	1
		EFF-2	7.6	270	5	3
		EFF-3	7.6	265	4	2

NR - No Results
Footnotes on page 28

Table 1. (continued) LABORATORY ANALYSIS

$T\text{-}PO_4$ (mg/l)	COD (mg/l)	TOC (mg/l)	TC/100 ml	FC/100 ml
4.8	64	23.5	1.2×10^6	2.0×10^5
3.6	16	11	6.0×10^5	5.0×10^3
3.6	24	13	4.0×10^5	3.0×10^3
4.1	44	21	0	0
4.0	16	9	0	0
3.34	83	20	0	0
1.10	71	19	0	0
1.62	75	24	0	0
3.3	21	10	0	0
1.83	27	9	0	0
0.95	27	9	0	0

FOOTNOTES: For Tables 1 and 5

a. Samples extraordinarily clear; not typical. Zero colony for 0.01 ml sample.

b. Estimated, non-ideal colony count (ENICC) 18 organisms per 0.1 ml sample.

c. ENICC - 115 org. per 0.1 ml

d. ENICC - 3 org. per 1.0 ml

e. Zero colony count per 0.1 ml

f. Zero colony count per 1.0 ml

g. ENICC - 107 org. per 0.01 ml and ENICC - 11 org. per 0.001 ml

h. Data for this and succeeding dates reflect sample system changes.

i. ENICC - 80 org. per 0.0001 ml

j. ENICC - 17 org. per 0.001 ml

k. Grass in sample.

l. Suspect methanol contamination.

m. ENICC - 3 org. per 0.011 ml

n. ENICC - 8 org. per 0.011 ml

o. ENICC - 5 org. per 0.01 ml

p. ENICC - 7 org. per 0.01 ml

q. ENICC - 84 org. per 0.1

r. ENICC - 9 org. per 0.01 ml

s. ENICC - 9 org. per 1.0 ml

t. Zero colony per 0.01 ml

u. ENICC - 7 org. per 1.0 ml

v. Microstrainer effluent used in backwash system.

w. Backwash system plugged after 10 min. of operation; backwash then switched to city water

x. Valve between influent chamber and influent sampler found to be clogged with debris.

(A) Cells/100 ml x 10^5 TC Total coliform

(B) Cells/100 ml x 10^4 FC Fecal coliform

INC Increase

NR No Results

SECTION VI
DISCUSSION OF RESULTS

Drainage Area - Rainfall and Runoff

The 4.5 hectare (11.2 acre) drainage area shown in Fig. 7 and Fig. 8 is served by combined sewers. Rainfall intensity-return frequency curves for the drainage area were furnished by the Philadelphia Water Dept. and are shown in Fig. 9 The drainage area can be characterized by a maximum calculated runoff coefficient of 61% using the rational method. The dry weather (sanitary) flow is shown in Fig. 10

Table 2 shows the hydrologic characteristics measured for the 27 storms for 1973 and 1974 (does not include the three synthesized hydrant storms) during microstrainer operation. Rainfall intensities were measured with a rain gauge located about 100 meters from the test site. The rain gauge was a 15.4 cm (4.8 in) dual traverse, 6 hours universal rain gauge, manufactured by Belfort Instrument Co.

The flow through the slot type regulator to the intercepting sewer was approximately 55 cu m/hr (0.35 mgd) based on the opening; however, at the end of June the slot regulator was replaced by a fluidic regulator which diverted a constant flow, under the storm conditions encountered, of 62 cu m/hr (0.39 mgd) to the interceptor. This value was extrapolated from a Philadelphia Water Dept. calibration curve for the fluidic regulator. The excess combined sewage overflowed into the concrete impoundment trough containing the three pumps which fed the microstrainer. The remainder overflowed a combination trapezoidal-rectangular weir to the creek. The trough and weir arrangement impounded about 15 cu m (4000 gallons) of combined sewer overflow.

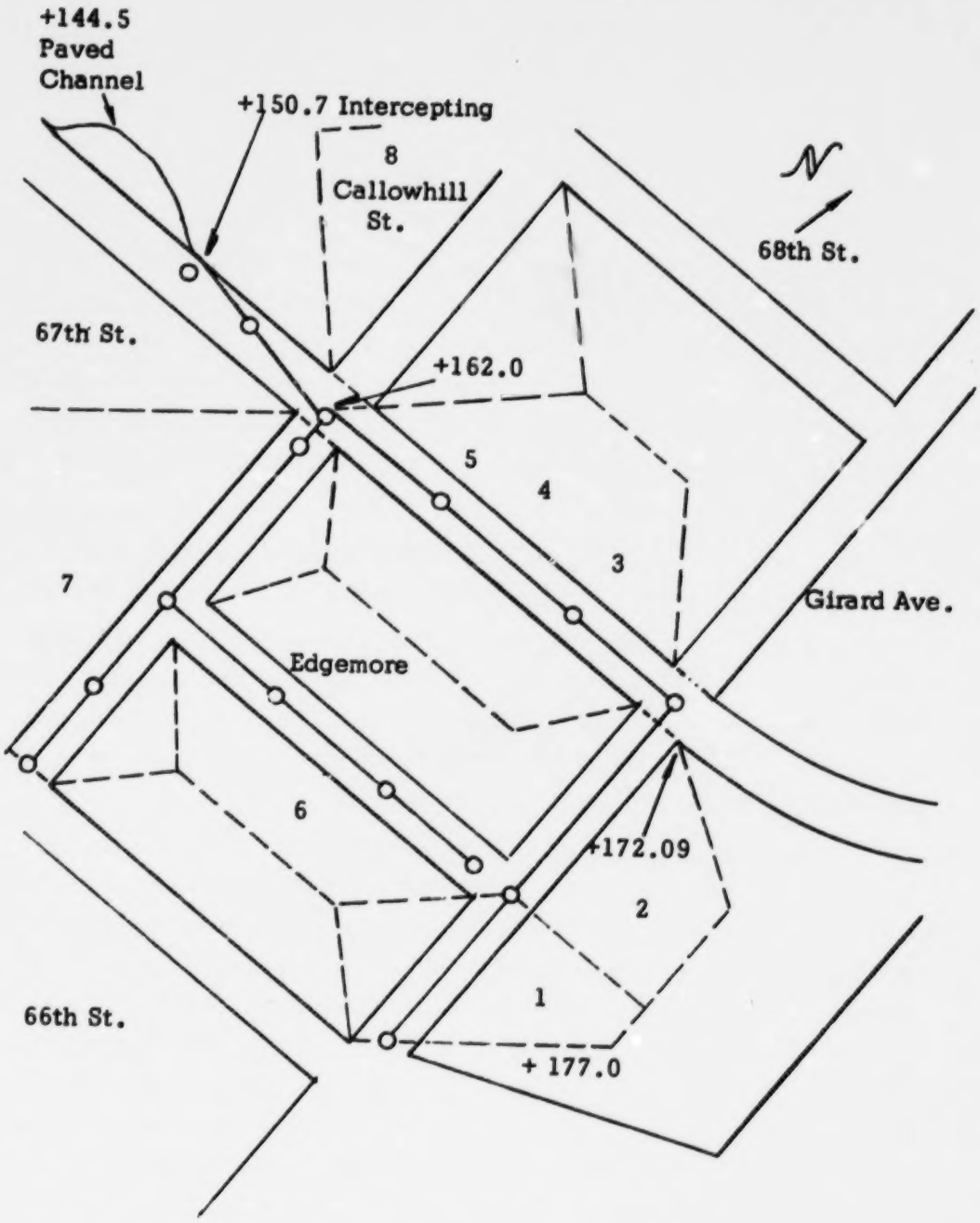

Figure 7

Outfall
67th & Callowhill

Figure 8
Drainage Area - within 200 ft of Test Site

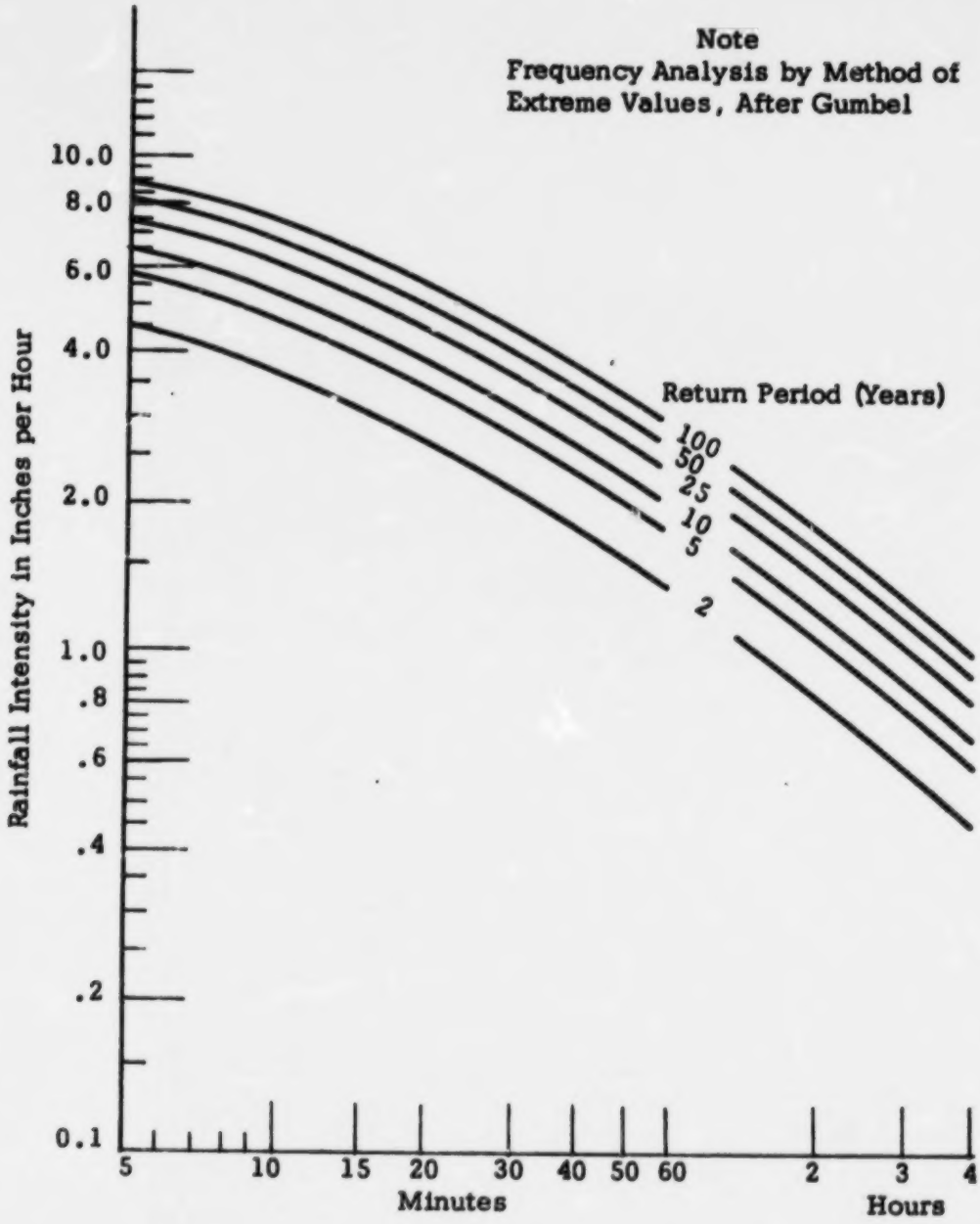

Figure 9
Rainfall Intensity - Philadelphia, Pennsylvania
1903-1951

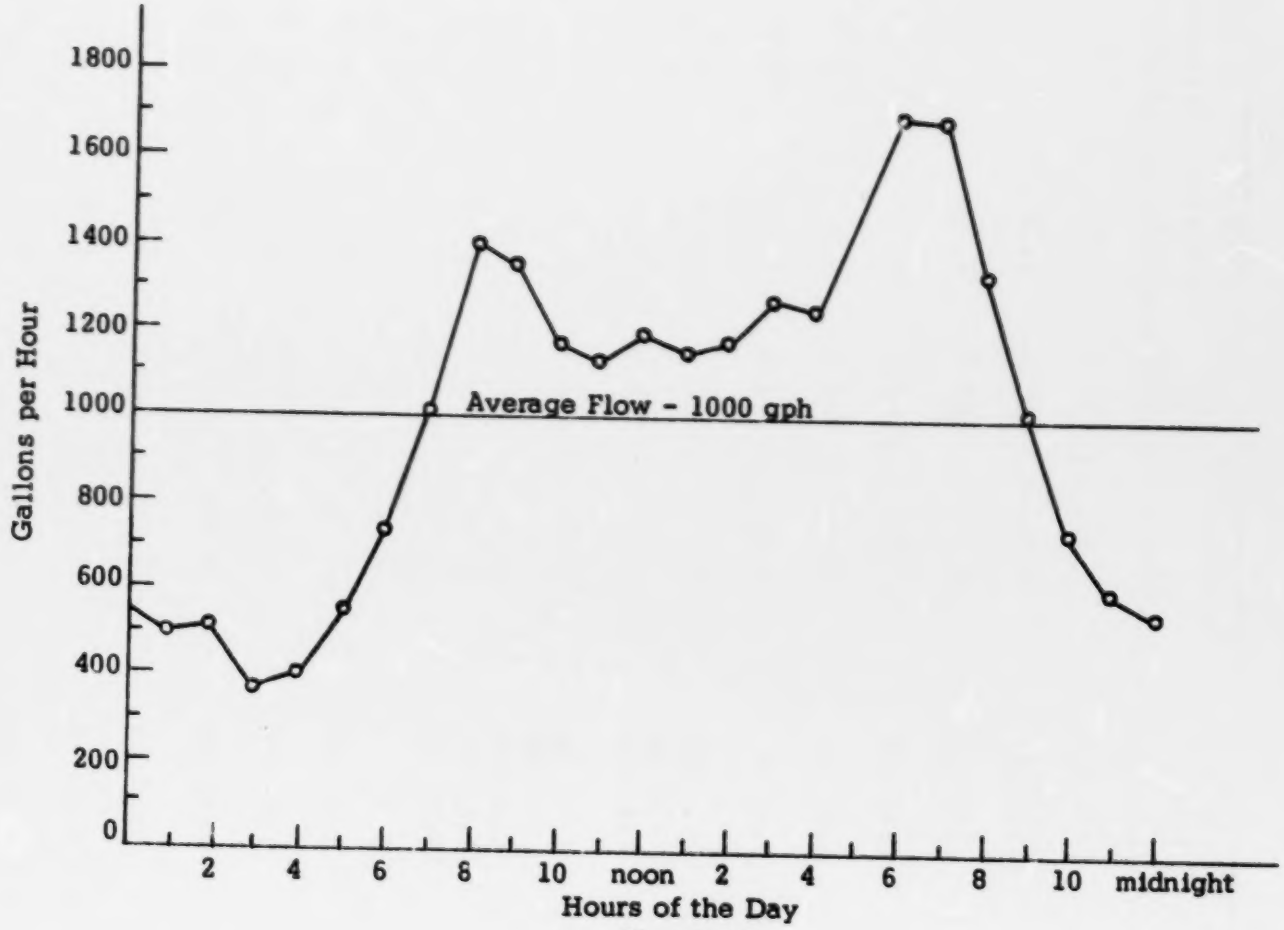

Figure 10
Hourly Variations, Sanitary Flow, 67th & Callowhill Sts. Sewer
(City of Philadelphia Data)

Table 2. HYDROLOGIC DATA

Date	Start-up time	Rainfall* (cm)	Max.storm flow (cu m/hr)	5 Min. intensity (cm/min)	10 Min. intensity (cm/min)
4/26/73	6:35 PM	0.46	211.4	1.22	1.22
4/27/73	12:05 AM	0.76	211.4	3.05	1.98
5/3 /73	3:00 PM	0.63	259.8	6.10	3.51
5/9 /73	4:00 PM	3.12	1359.4	36.58	35.05
5/17/73	6:00 AM	0.51	211.4	0.91	0.91
5/20/73	12:00 N	0.28	211.4	1.52	1.07
5/27/73	12:15 AM	0.25	211.4	0.61	0.61
	9:50 AM	0.25	141.9	0.91	0.76
	2:45 PM	0.25	211.4	0.61	0.61
5/28/73	7:15 AM	0.74	209.5	2.74	1.83
6/22/73	8:25 AM	0.25	141.9	0.61	0.61
	12:00 N	1.12	178.4	2.44	2.44
	12:30 PM	0.56	110.9	1.22	0.91
6/29/73	5:00 AM	2.44	322.3	5.49	5.08
	2:30 PM	0.74		4.57	2.79
7/11/73	3:00 PM	2.00	390.0	6.10	5.08
7/15/73	3:00 PM	1.02	167.5	1.83	1.52
8/1 /73	6:30 PM	1.52	677.3	7.37	6.35
8/2 /73	4:30 PM	1.37	481.3	6.60	4.83
10/2 /73	5:00 PM	0.81	209.5	3.05	2.59
11/28/73	3:00 PM	0.79	209.5	3.05	3.05
12/5 /73	11:00 AM	0.25	141.9	0.91	0.76
	8:00 PM	1.27	198.5	5.18	3.51

Table 2. (continued) HYDROLOGIC DATA

Date	Start-up time	Rainfall* (cm)	Max.storm flow (cu m/hr)	5 Min. intensity (cm/min)	10 Min. intensity (cm/min)
12/13/73	10:45 PM	0.30	141.9	1.22	1.07
12/20/73	10:55 PM	0.46	209.5	2.44	1.52
12/26/73	6:45 PM	0.08	211.4	.72	.66
1/3 /74	10:30 AM	Fire hydrant	209.5	Fire hydrant	Fire hydrant
1/30/74	11:00 AM	Fire hydrant	199.5	Fire hydrant	Fire hydrant
1/31/74	11:00 AM	Fire hydrant	209.5	Fire hydrant	Fire hydrant

* Total rainfall during microstrainer operation.

The influent flow rate was continuously measured by a venturi flow meter and recorded on a strip chart. The level in the impoundment trough was also continuously monitored with a bubbler tube system. The storm flows listed in Table 2 were equal to the maximum flow over the weir based on readings from the level recorder, the flow pumped to the microstrainer facility and the flow to the interceptor minus the dry weather flow.

The average maximum storm flow encountered was 271 cu m/hr (1.72 mgd) with a high of 1359.4 cu m/hr (8.6 mgd) and a low of 110.9 cu m/hr (0.7 mgd).

Coagulation Study

Nineteen different polyelectrolytes were evaluated individually and in combination with inorganics and powdered coal. A list of the coagulants used in the study follows:

Coagulants

A. Anionic Polyelectrolytes
   1. Atlasep 2A2
   2. Atlasep 3A3
   3. Atlasep 4A4
   4. Betz 1130
   5. Hercofloc 816
   6. Hercofloc 836
   7. Hercofloc 822

B. Cationic Polyelectrolytes
   1. Dow Purifloc C-31
   2. Atlasep 105C
   3. Betz 1150
   4. Betz 1160
   5. Betz 1170
   6. Betz 1175
   7. Betz 1190
   8. Betz DK-522

9. Hercofloc 810
10. Hercofloc 814
11. Hercofloc 828.1

C. Non-Ionic Polyelectrolytes
1. Dow Purifloc N-11

D. Inorganic Coagulants
1. Alum
2. Ferric Chloride
3. Lime

E. Organics
1. Powdered Coal

The polyelectrolytes and inorganic coagulant alone and in combinations were screened in Crane-Cochrane's laboratory on a sample from the microstrainer influent chamber by jar tests for various concentrations on liter samples of combined sewer overflow using a gang stirrer. The samples were fast or flash mixed for one minute followed by ten seconds of slow mixing. The samples which exhibited the best coagulation characteristics were then passed through a 10 cm (4 in) high by 5 cm (2 in) diameter filter tube fitted with a Mark "0" screen. The volume of the sample which passed the test tube in 9 seconds was recorded. 100 ml of the effluent was then passed through a 0.45 micron millipore membrane filter and the time was recorded. Examples of the better results are shown in contrast to a background sample of zero concentration of polyelectrolyte:

Type	Initial Conc mg/l	Vol(ml)/9 sec	Millipore Time(min/ 100 ml)
Atlasep 105C	1.5	380	31
Purifloc C-31	4.0	205	22
Betz 1150	3.0	351	33
Straight	0.0	140	4

The results of the coagulation study are given in the Appendix. Atlasep 105C and Betz 1150 were chosen as the most

suitable polymers to be employed at the microstrainer. Both polymers exhibited large, strong flocs, and increased the throughput in the bench study as well as showing, the best visual reduction of turbidity (best approach under limited manpower conditions). Any residual polyelectrolyte which passed through the Mark "0" screen along with the very fine turbidity left in the solution would clog the 0.45 micron Millipore filter membrane. This resulted in very slow rates through the filter membrane.

Atlasep 105C and Betz 1150 were then tried on the 23 cm (9 in) I.D. by 23 cm (9 in) long, laboratory pilot microstrainer located at the test site. The influent to this unit was the combined sewer overflow stored in a 20 cu m (5000 gallon) covered steel tank located behind the microstrainer building. It was impossible to duplicate the dynamic conditions of the full scale microstrainer with the small unit; however, the unit did exhibit good coagulation in the inlet chamber resulting in an increase of both turbidity reduction and throughput.

Based on these results, the full scale microstrainer at the test site was operated with polyelectrolyte addition for the last three months of Phase III beginning with the storm of November 28, 1973 and ending on January 31, 1974. Atlasep 105C was used during four different storm events at an initial concentration of 1.5 mg/l. These storms occurred on November 28, December 5 (two storms), and December 13, 1973. Betz 1150 was also used during four different storms-December 20 and 26, 1973 and January 30 and 31, 1974. The storms of January 30 and 31, 1974 were synthesized by opening a fire hydrant.

Both coagulants were added to provide an initial concentration of 1.5 mg/l; however, during the hydrant induced storm of January 31, 1974, the concentration was varied as follows: 0.25 mg/l, 0.5 mg/l, and 1.0 mg/l. As the concentration

was increased the percent removal increased but the throughput decreased slightly. This is shown in Table 3.

In general, coagulant addition improved the performance of the microstrainer by increasing both the throughput and the percent SS removal as well as consistently discharging an effluent SS of less than 40 mg/l. A more thorough discussion of coagulated vs uncoagulated conditions will be presented later.

Throughput

The throughput across the microstrainer was dependent on the influent flow rate, the influent suspended solids, the differential between the influent and effluent chambers, polymer type and concentration, and the drum speed. Since the inflow, differential and the drum speed become constant once the unit comes to equilibrium, the throughput is then dependent on influent SS (size, shape, and concentration) which would determine the porosity and thickness of the filter mat on the screen. The throughput generally increased with time since SS concentration decreased with the length of the storm due to the initial flush phenomena. It should be noted that the radial flow rates (throughput) listed in Table 3 are average values based on the pump flow from the impoundment trough minus the average value of the influent chamber overflow.

The average throughput for the microstrainer operating without coagulant was 38.4 m/hr (16.0 gpm/sq ft) with a high of 56.4 m/hr (23.0 gpm/sq ft) and a low of 16.8 m/hr (6.8 gpm/sq ft). The average throughput for operation with coagulant was 87.5 m/hr (36.0 gpm/sq ft) with a high of 95.4 m/hr (39.0 gpm/sq ft) and a low of 54.6 m/hr (22.3 gpm/sq ft).

In the Phase II Report (2), throughputs ranging from 85.6 to 110.0 m/hr (35-45 gpm/sq ft) were reported and were never achieved in Phase III.

Date	Start-up time	MS operation (min)	Maximum stormflow (cu. m).	Maximum differential (cm)
4/26/73	6:35 PM	45	211.4	61.0
4/27/73	12:05 AM	45	211.4	61.0
5/ 3/73	3:00 PM	24	259.8	61.0
5/ 9/73	4:00 PM	48	1359.4	61.0
5/17/73	8:00 AM	45	211.4	61.0
5/20/73	12:00 N	45	211.4	61.0
5/27/73	12.15 AM	30	211.4	61.0
	9:50 AM	30	141.9	47.5
	2:45 PM	30	211.4	61.0
5/28/73	7:15 AM	32	209.5	61.0
6/22/73	8:25 AM	48	141.9	61.0
	12:00 N	48	178.4	61.0
	12:30 PM	48	110.9	61.0
6/29/73	5:00 AM	48	322.3	61.0
	2:30 PM	45	209.5	61.0
7/11/73	3:00 PM	54	390.0	61.0
7/15/73	3:00 PM	52	167.5	53.2
8/ 1/73	6:30 PM	30	677.3	55.9
8/ 2/73	4:30 PM	48	481.3	61.0
10/ 2/73	5:00 PM	35	209.5	61.0
11/28/73	3:00 PM	20	209.5	61.0
12/ 5/73	11:00 AM	25	141.9	61.0
	8:00 PM	30	198.5	61.0

Table 3. (continued) MICROSTRAINER DYNAMIC PERFORMANCE DATA

Maximum drum speed (rpm)	Throughput m/hr	Flow through MS (cu m)	Coagulant conc. (mg/l)	Suspended solids removal %
6.0	45,0	32.6	0	59
6.0	26.4	19.1	0	69
6.0	26.4	19.1	0	80
6.0	31.2	22.6	0	73
6.0	25.8	18.7	0	31
6.0	21.0	15.2	0	59
6.0	53.4	38.7	0	82
6.0	27.6	20.0	0	61
6.0	49.2	35.6	0	INC
6.0	29.4	21.3	0	67
6.0	16.8	12.2	0	85
6.0	51.6	37.4	0	84
6.0	51.6	37.4	0	80
6.0	33.0	23.9	0	49
6.0	36.0	26.1	0	50
6.0	46.2	33.5	0	28
6.0	45.0	32.6	0	17
6.0	54.0	39.0	0	59
6.0	42.6	30.9	0	67
6.7	56.4	40.9	0	64
6.7	54.6	39.6	1.5	76
6.7	95.4	69.1	1.5	65
6.7	95.4	69.1	1.5	79

Table 3. (continued) MICROSTRAINER DYNAMIC PERFORMANCE DATA

Date	Start-up time	MS operation (min)	Maximum stormflow (cu m)	Maximum differential (cm)
12/13/73	10:45 PM	30	141.9	61.0
12/20/73	10:55 PM	25	209.5	61.0
12/26/73	6:45 PM	15	211.4	61.0
1/ 3/74	10:30 AM	6	209.5	61.0
1/30/74	11:00 AM	45	199.5	61.0
1/31/74	11:00 AM	45	209.5	61.0

(a) Unit broke down after 1 sample was taken.

Table 3. (continued) MICROSTRAINER DYNAMIC PERFORMANCE DATA

Maximum drum speed (rpm)	Throughput m/hr	Flow through MS (cu m)	Coagulant conc. (mg/l)	Suspended solids removal %
6.7	95.4	69.1	1.5	94
6.7	95.4	69.1	1.5	77
6.7	95.4	69.1	1.5	67
6.7	(a)	69.1	0	26
6.7	75.5	54.8	1.5	94
6.7	89.4	64.7	1.0	94
	91.1	66.1	0.5	90
	92.4	67.0	0.25	77

A microscopic examination of backwash samples for both coagulated and uncoagulated conditions on separate occasions showed that the average particle size retained by the Mark "O" screen for the coagulated sample was larger, as was expected. The backwash rate was 1.8 cu m/hr (8 gpm) and the SS concentrations were 756 mg/l for the coagulated sample and 732 mg/l for the uncoagulated sample. The coagulated backwash sample showed that 8% of the particles were greater than 27 microns while the uncoagulated backwash sample showed only 3% of the particles were greater than 27 microns. The average particle size retained for the coagulated backwash sample was 9.5 microns and for the uncoagulated sample, 3.9 microns. The particle size analyses are given in Table 4 and a plot of cumulative percent vs. particle size for both the coagulated and uncoagulated backwash sample is shown in Fig. 11. Although this data is based on two separate storm occurrences, microscopic examinations had been made before on other storms in preparation for particle size counting and had shown the same basic particle size distributions.

It is not surprising that coagulation increased the throughput. The mat of coagulated solids on the screen would not be as compact due to larger void spaces and thus would allow more liquid to pass through the screen. It should not be inferred that coagulation will increase throughput in every application; the increased throughput along with an increased SS removal for this application showed that the floc was rigid in nature and able to withstand higher flow rates. In other applications the floc may be more fragile depending on the nature of the particles encountered and the coagulant chosen; therefore, coagulation tests should be performed at each installation.

Table 4. BACKWASH PARTICLE SIZE ANALYSIS

Uncoagulated sample - January 3, 1974

Size, (Microns)	Number	Percent by count	Cumulative percent
0.07	77	46.7	100.0
0.14	26	15.8	53.3
0.7	19	11.5	37.5
3.0	11	6.7	26.0
7.0	24	14.5	19.3
14.0	3	1.8	4.8
27.0	1	0.6	3.0
41.0	1	0.6	2.4
61.0	1	0.6	1.8
109.0	1	0.6	1.2
136.0	1	0.6	0.6

Coagulated sample - December 26, 1973, Betz 1150 at 1.5 mg/l

0.07	131	30.2	100.0
0.14	95	21.9	69.7
0.7	53	12.2	47.8
3.0	45	10.4	35.6
7.0	45	10.4	25.2
14.0	6	1.4	14.8
20.0	9	2.1	13.4
27.0	11	2.5	11.3

Table 4. (continued) BACKWASH PARTICLE SIZE ANALYSIS

Size, (Microns)	Number	Percent by count	Cumulative percent
34	10	2.3	8.8
41	4	0.9	6.5
48	2	0.5	5.6
54	2	0.5	5.1
61	1	0.2	4.6
67	1	0.2	4.4
82	2	0.5	4.2
95	1	0.2	3.7
100	1	0.2	3.5
136	2	0.5	3.3
163	1	0.2	2.8
170	4	0.9	2.6
176	1	0.2	1.7
190	1	0.2	1.5
340	1	0.2	1.3
510	1	0.2	1.1
1190	2	0.5	0.9
1875	1	0.2	0.4
2900	1	0.2	0.2

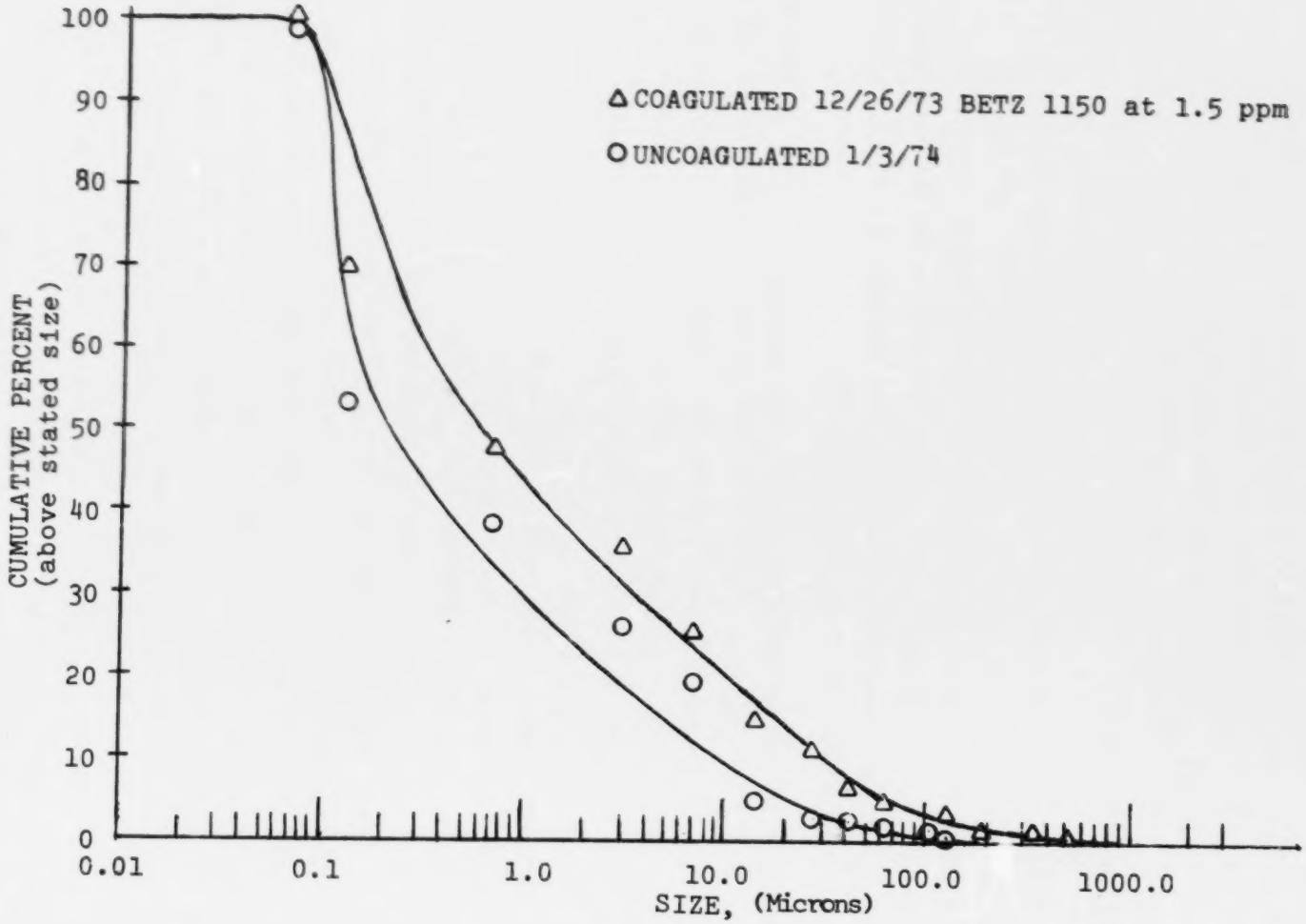

Figure 11
Cumulative Percent vs. Particle Size

Suspended Solids Removal

The suspended solids (SS) removal performance for the microstrainer on the uncoagulated influent is shown in Table 5. The average percent removal was 70% for an average influent SS of 159 mg/l. The average effluent SS concentration was 48 mg/l with a range of 9 mg/l to 89 mg/l. A plot of percent solids removal vs. influent suspended solids (Fig. 12) shows that there is a trend for the percent removal to increase as the influent SS level increases which indicates that the effluent SS level is fairly constant. Fig. 13 shows that the microstrained SS in the effluent was consistently below 60 mg/l regardless of the influent concentration. The lowest effluent concentrations were obtained at the lower influent SS levels.

The addition of polyelectrolyte when compared to no addition increased the percent removal of SS as well as giving a lower effluent SS concentration (Table 6). The average influent SS for this period decreased to 106 mg/l. The SS removal achieved was 78% and the average effluent SS concentration was 23 mg/l with a range of 4-49 mg/l. Fig. 12 shows that the percent removal did not follow any pattern with an increase in influent solids concentration, but compositing the samples may have reduced the marked difference between influent and effluent SS concentrations and also the influent SS level was lower during the period when polyelectrolyte was being added. Fig. 13 indicates a trend toward an increase in effluent solids with an increase in influent solids; however, since two different polyelectrolytes were used on only eight storms, it is difficult to draw any firm conclusions. The Betz 1150 seemed to give the best effluent quality, but it was added to a raw combined sewer overflow of much lower SS levels (two of the flows were synthesized by a hydrant). In general, the polyelectrolyte addition did give a superior effluent quality while also markedly increasing the

throughput. Further work is necessary to confirm these results.

Organic Solids and Total Phosphate Removals

The organic solids and total phosphate ($T\text{-}PO_4$) removals for the coagulated and uncoagulated conditions of individual storms are listed in Tables 5 and 6. A summary of average values follows:

Uncoagulated

	VSS (mg/l)	COD (mg/l)	TOC (mg/l	$T\text{-}PO_4$ (mg/l)
Influent	50	133	38	3.33
Effluent	16	84	26	2.84
% Removal	68	37	32	15
Coagulated				
Influent	58	154	40	2.58
Effluent	12	66	19	1.95
% Removal	79	57	52	24

The reduction of VSS closely parallels the reduction of total SS as would be expected. It is interesting to note that the percent VSS/SS ranges from 30-55% which is much lower than the normal % VSS/SS of sewage treatment plant influents (60-85%) and is indicative of the contribution of inorganics in storm runoff. The lower removals of TOC, COD, and $T\text{-}PO_4$ across the microstrainer (as compared to VSS) is attributed to the suspended organic and inorganic material which is removed by the screen since the microstrainer removes very little, if any dissolved material and these parameters (TOC, COD and $T\text{-}PO_4$) include dissolved matter. The TOC and COD reduction increased by 20% with polyelectrolyte addition. However, the substantial increase in TOC and COD reduction with polyelectrolyte addition suggests that some of the dissolved and colloidal material had coagulated; however, this is speculative since dissolved solids were not measured.

Table 5. MICROSTRAINER REMOVAL PERFORMANCE

No coaqulant addition

Date of storm	Start-up time	SS In	SS Out	SS Rem	VSS In	VSS Out	VSS Rem	$T\text{-}PO_4$ In	$T\text{-}PO_4$ Out	$T\text{-}PO_4$ Rem
		mg/l		%	mg/l		%	mg/l		%
4/26/73	6:35PM	22	9	59	11	8	27	3.6	2.1	42
4/27/73	12:05AM	291	89	69	84	26	69	3.2	1.4	56
5/3 /73	3:00PM	260	50	80	64	22	66	4.1	4.8	INC
5/9 /73	4:00PM	176	48	73	52	6	88	3.0	1.8	40
5/17/73[h]	8:00PM	72	50	31	48	40	17	3.3	2.6	21
5/20/73	12:00N	132	54	59	71	27	62	4.8	4.8	0
5/27/73	12:15AM	155	28	82	48	13	73	4.3	3.7	14
	9:50AM	97	38	61	36	14	61	3.8	3.2	16
	2:45PM[k]	70	77	INC	41	9	78	4.9	3.1	37
5/28/73	7:15AM	174	58	67	40	14	65	3.0	2.2	36[l]
6/22/73	8:25AM[v]	256	39	85	111	20	82	5.0	4.3	14
	12:00N [v]	293	48	84	123	15	88	5.6	4.0	29
	12:30PM[v]	238	47	80	101	17	83	2.6	2.5	4
6/29/73	5:00AM[v]	92	47	49	17	8	53	2.0	1.6	20
	2:30AM[v]	113	56	50	29	15	48	2.4	2.9	INC
7/11/73	3:00PM[v]	54	39	28	16	17	INC	1.5	2.5	INC
7/15/73	3:00PM[w]	23[x]	19	17	8	9	INC	0.6	1.6	INC
8/1/73	6:30PM	154	63	59	54	26	52	4.0	4.4	INC
8/2/73	4:30PM	78	26	67	32	12	62	2.2	1.8	18
10/2/73	5:00PM	53	19	64	40	14	65	1.3	0.75	42
1/3/74	10:30AM	68	50	26	26	11	58	4.8	3.6	25

See page 28 for footnotes.

Table 5. (continued) MICROSTRAINER REMOVAL PERFORMANCE

No coagulant addition

COD			TOC			TC (A)			FC (B)		
In	Out	Rem	In	Out	Rem	In	Out	Rem	In	Out	Rem
mg/l		%	mg/l		%			%			%
33	29	14	9	7	22	5.0	<0.1[a]	98+	<1.0[a]	1.0	0
190	142	25	55	34	38	6.8	<0.01[e]	99+	1.8	0.01[f]	99+
171	127	26	32	28	12	1.2	<0.1[e]	99+	.03[d]	<0.01[f]	67+
119	95	20	26	20	23	11.0	0.46	96	2.3	.048	94
124	88	29	34	26	24	3.4[i]	2.5[i]	26	0.38	0.27	29
181	169	8	46	38	18	<8.0[m]	8.0	0	0.67	1.7[j]	INC
108	84	22	28	26	8	0.3	0.021[f]	93	7.3[n]	5.8	21
100	60	40	22	14	36	2.0[f]	0.22	81	5.0[o]	5.4	INC
116	88	24	29	21	27	0.7[j]	0.026	96	47.0	8.4[q]	82
5920[l]	96	NR[l]	1600[l]	24	NR[l]	0.9[r]	0.009[s]	99	<1.0[t]	0.07[u]	< 93
284	220	22	104	87	16	53.0	1.9	96	>6.0	0.9	> 85
224	64	71	64	21	67	41.0	13.0	68	2.0	0.27	86
196	48	76	45	17	62	35.0	5.5	84	4.6	1.0	78
57	57	0	22	19	14	16.0	5.9	63	1.4	.74	47
64	52	19	30	18	39	18.0	64.0	INC	0.71	5.1	INC
4	0	100	15	15	0	8.9	1.4	84	15.0	0.15	99
42	38	10	12	15	INC	6.2	6.0	3	0.5	0.6	INC
125	82	34	39	26	33	45.0	5.0	89	3.2	0.7	68
64	16	75	22	16	27	26.0	15.0	42	1.8	0.7	61
88	48	46	31	18	42	NR	NR	NR	NR	NR	NR
64	20	69	24	12	50	12.0	5.0	58	20.0	0.4	98

Table 6. MICROSTRAINER REMOVAL PERFORMANCE

Coagulant addition

Date of storm	Start-up time	SS In	SS Out	SS Rem	VSS In	VSS Out	VSS Rem	T-PO_4 In	T-PO_4 Out	T-PO_4 Rem
		mg/l		%	mg/l		%	mg/l		%
11/28/73	3:00PM	204	49	76	101	30	70	2.59	1.06	59
12/5 /73	11:00AM	108	38	65	54	8	85	3.0	1.35	55
	8:00PM	171	36	79	150	30	80	2.77	2.33	14
12/13/73	10:45PM	84	5	94	39	4	90	2.21	1.3	41
12/20/73	10:55PM	65	15	77	18	0	100	3.0	2.9	3
12/26/73	6:45PM	86	28	67	52	20	62	0.88	0.66	25
1/30/74	11:00AM	72	4	94	31	4	87	4.1	4.0	2
1/31/74	11:00AM	55	6	89	21	2	90	2.0	2.0	0

(A) Cells/100 ml x 10^5
(B) Cells/100 ml x 10^4

Table 6. (continued) MICROSTRAINER REMOVAL PERFORMANCE

COD			TOC			TC (A)			FC (B)		
In	Out	Rem	In	Out	Rem	In	Out	Rem	In	Out	Rem
mg/l		%	mg/l		%						
326	155	52	71	20.5	71	NR	NR	NR	NR	NR	NR
91	61	33	38	26.	32	NR	NR	NR	NR	NR	NR
NR	NR	NR	45	22.	51	NR	NR	NR	NR	NR	NR
92	64	30	32	21.	34	9.7	.09	99+	50.0	0.13	99+
296	75	75	67	27.	60	13.0	4.0	69	60.0	8.0	87
1600	800	50	28	17.6	37	8.0	NR	NR	2.0	NR	NR
44	16	67	21	9.	57	0	0	0	0	0	0
76	25	67	21	9.	57	0	0	0	0	0	0

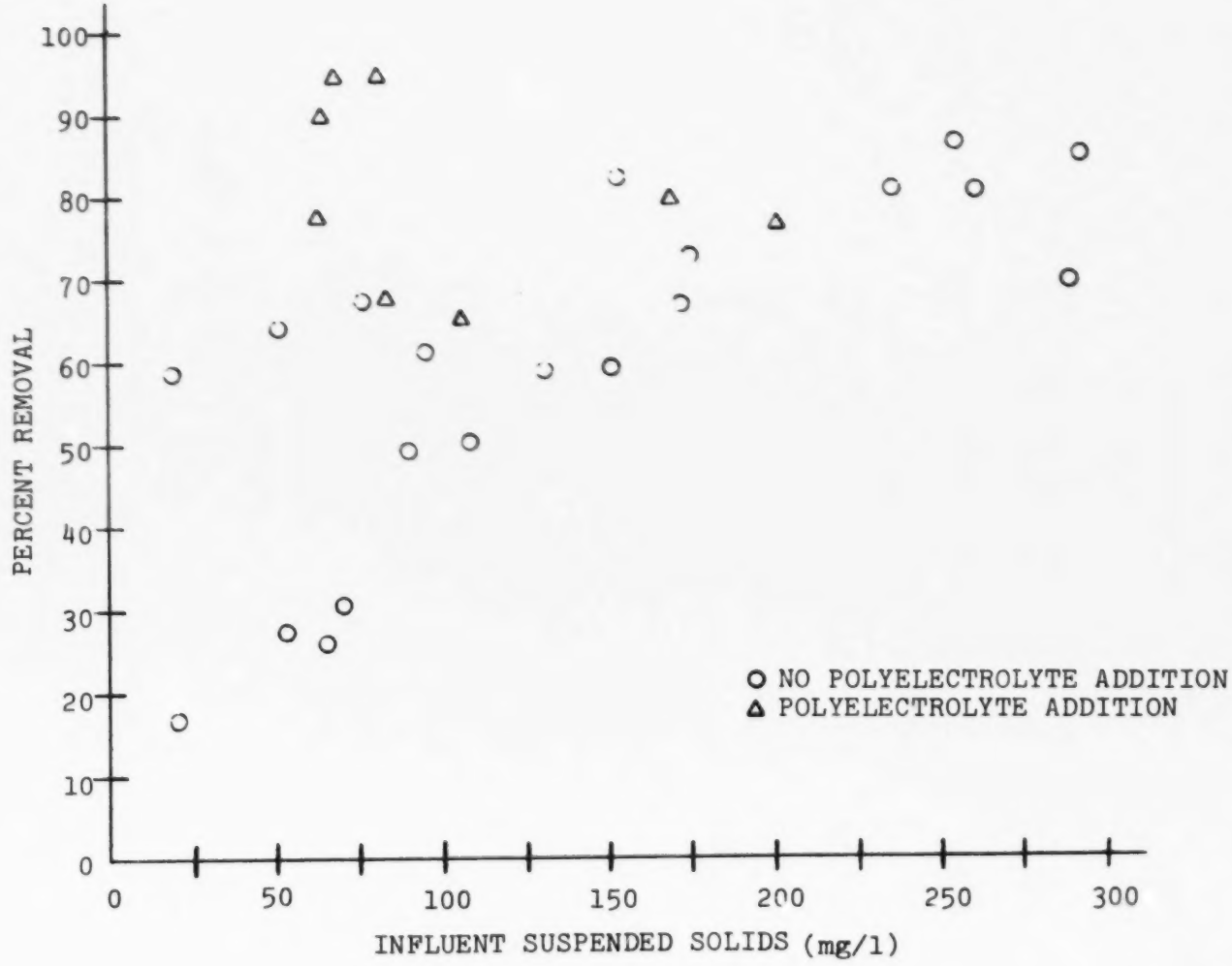

Figure 12
Percent Removal vs. Influent Suspended Solids

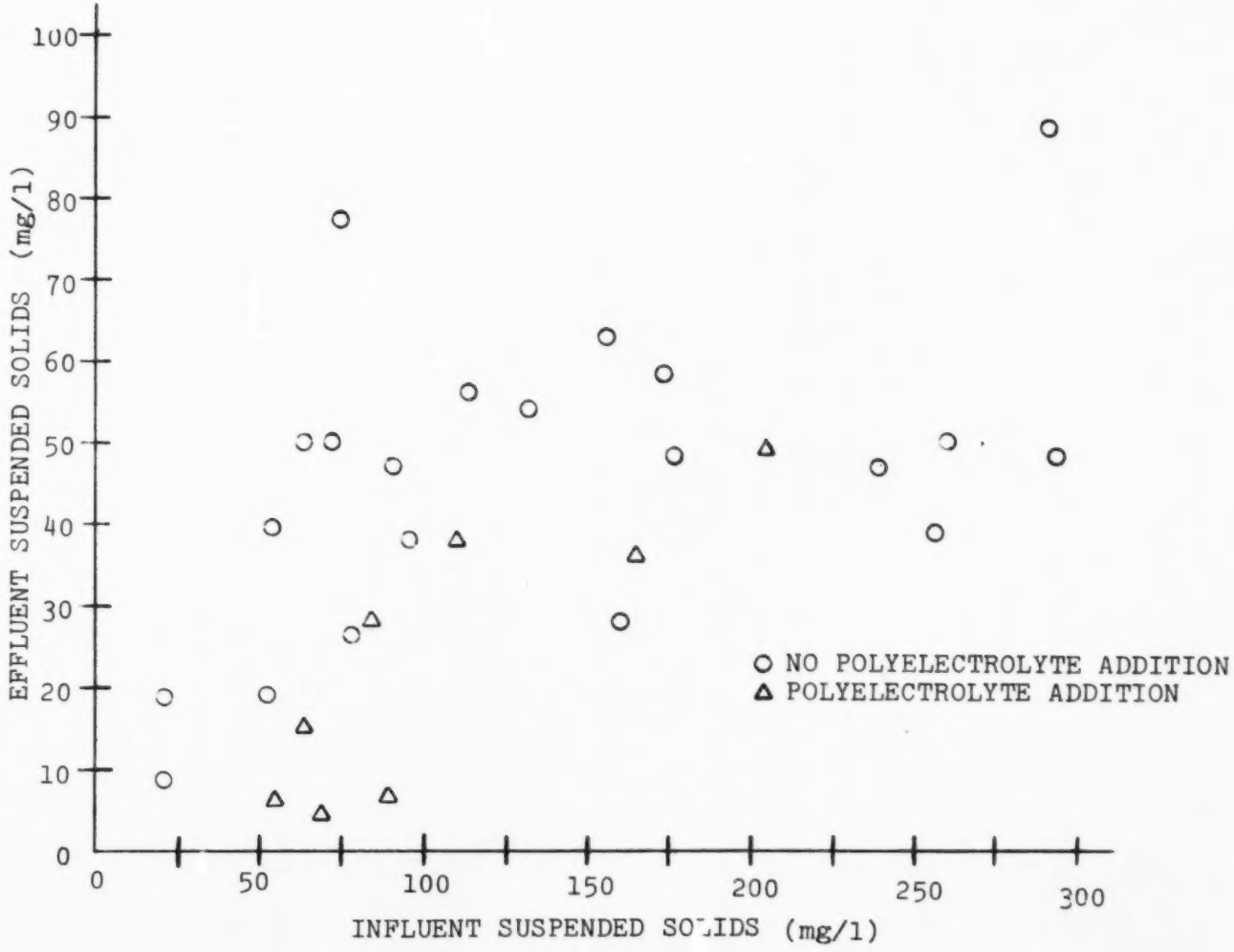

Figure 13
Effluent Suspended Solids vs. Influent Suspended Solids

Polyelectrolyte addition did not dramatically enhance phosphate removal. The phosphate removal probably resulted from removal of the solid or adsorbed phosphates on the suspended matter. The phosphate removal increased by 9% with polyelectrolyte addition which paralleled the SS removal increase of 8%.

Coliform Removal By A Microstrainer

Total coliform (TC) and fecal coliform (FC) counts were performed on both the influent and effluent composite samples of the microstrainer. The membrane filter technique in STANDARD METHODS (4) was followed for coliform determinations. The samples were macerated to reduce the possibility of clumping and of isolating cells from the nutrient broth by a solids barrier. Because the coliform levels in the combined sewer overflow varied by as high as five orders of magnitude, it was difficult to select a dilution range which would assure an ideal colony count; therefore, the coliform counts listed in Table 1 are often not ideal as can be seen by the number of footnotes.

In 17 out of 22 storms, there was a reduction of fecal coliform across the microstrainer ranging from 21% to greater than 99%,and in 20 out of 22 storms, there was a reduction of total coliform ranging from 3% to greater than 99% (Table 5).

Although the Mark "O" screen openings are 23 microns, the formation of a mat of solids reduces the apertures substantially. The particle size analysis on the backwash showed that the microstrainer was able to remove particles as small as 0.07 microns. In the membrane filter method a known sample volume is passed through a 0.45 micron membrane filter to retain coliforms; therefore, it is not surprising that there was a coliform reduction across the screen.

Disinfection With Chlorine and Ozone

One of the primary functions of Phase III was to reinforce previous data from Phase II that the microstrained effluent was more amenable to disinfection using both chlorine (Cl_2) in the form of sodium hypochlorite and ozone (O_3) than the raw combined sewer overflow and that disinfection could be accomplished in short contact times.

The results listed in Tables 7 and 8 show that for the seven storm events when Cl_2 was added simultaneously to both the influent and effluent that on five occasions a greater coliform kill was obtained for the effluent sample and at lower Cl_2 concentrations.

The results of Phase III show that by using the high rate Cl_2 contact chamber both total and fecal coliform levels of less than 200 FC/100 ml and 1000 TC/100 ml (Philadelphia Water Dept. sewage treatment plant effluent standards) could be achieved with initial Cl_2 concentrations as low as 5 mg/l with 4.25 min. contact time for the raw combined sewer overflow and as low as 2.6 mg/l with 3.25 min. contact time with the microstrained effluent. For design purposes the recommended maximum chlorine concentrations that should be provided would be 12 mg/l for the raw combined sewer overflow and 6 mg/l for the microstrained effluent to insure adequate chlorine disinfection. Higher Cl_2 concentrations are necessary for the raw combined sewer overflow because of the higher Cl_2 demand and the larger amount and diameter of protective solids.

On four occasions samples of chlorinated effluent were collected after only 1.25 min. of contact time. In each case the surviving FC levels were less than 10 organisms/ 100 ml which was the same level achieved after 3.25 contact time. The surviving TC levels were higher for 1.25 min. contact time but still acceptable, especially at the lower

Table 7. DISINFECTION RESULTS

Raw Combined Sewer Overflow

Date	Time	TC (1)	FC (2)	Cl_2 Conc. (mg/l)
6/22/73	12:00 N	41.0	2.0	5.0
6/29/73	5:00 AM	16.0	1.4	12.0
	2:30 PM(4)	18.0	0.71	12.0
		18.0	0.71	12.0
		18.0	0.71	12.0
7/11/73	3:00 PM	8.9	15.0	5.0
7/15/73	3:00 PM	6.2	0.5	9.0
		6.2	0.5	9.0
8/1 /73	6:30 PM	45.0	3.2	5.1
8/2 /73	4:30 PM(5)	26.0	1.8	5.1
		26.0	1.8	5.1
10/2 /73	5:00 PM	NR	NR	5.0

(1) Cells/100 ml x 10^5
(2) Cells/100 ml x 10^4
(3) Cells/100 ml
(4) Samples taken after 15, 20, and 25 min. of operation.
(5) Samples taken after 15 and 30 min. of operation.
TC Total Coliforms
FC Fecal Coliforms
RES Residual
NR No Results
Cl_2 Chlorine

Table 7. (continued) DISINFECTION RESULTS

Cl_2 (mg/l)	pH	Contact time (min)	Surviving TC (3)	Surviving FC (3)
NR	8.6	4.25	1500	110
NR	7.1	4.25	500	< 10
7.0	7.3	4.25	100	< 10
7.0	7.2	4.25	230	< 10
9.0	7.3	1.25	140	< 10
0.0	8.6	4.25	134000	> 6000
5.0	6.8	4.25	60000	6000
5.0	6.9	4.25	56000	100
3.0	7.4	4.25	< 10	< 10
2.0	7.2	4.25	> 30000	> 6000
2.0	7.3	4.25	6700	200
1.5	NR	4.25	NR	NR

Table 8. DISINFECTION RESULTS

Effluent Date	Time	TC (1)	FC (2)	Cl_2 conc. (mg/l)	Cl_2 res. (mg/l)	pH	Det. time
6/22/73	12:00 N	13.0	0.27	5.0	NR	8.4	4.25
6/29/73	5:00 AM	5.9	0.74	5.0	NR	7.2	4.25
	2:30 PM	64.0	5.1	5.0	1.7	7.8	4.25
	(4)	64:0	5.1	5.0	1.7	7.7	4.25
		64.0	5.1	5.0	1.7	7.6	1.25
7/11/73	3:00 PM	1.4	0.15	5.0	3.0	9.7	4.25
7/15/73	3:00 PM	6.0	0.6	5.0	1.5	7.0	4.25
	(5)	6.0	0.6	5.0	1.5	7.2	4.25
8/1 /73	6:30 PM	5.0	0.7	5.6	4.0	7.2	4.25
8/2 /73	6:30 PM	15.0	0.7	5.6	0.0	7.3	4.25
	(5)	15.0	0.7	5.6	1.5	7.2	4.25
10/2 /73	5:00 PM	NR	NR	2.6	1.5	NR	1.25
		NR	NR	2.6	1.5	NR	3.25
12/5 /73	11:00 AM	NR	NR	2.7	1.5	NR	1.25
		NR	NR	2.7	1.0	NR	3.25
12/20/73	10:55 AM	4.0	8.0	2.7	NR	NR	1.25

(1) Cells/100 ml x 10^5
(2) Cells/100 ml x 10^4
(3) Cells/100 ml
(4) Samples taken after 15, 20, and 25 min. of operation.
(5) Samples taken after 15 and 30 min. of operation.
TC Total Coliforms
FC Fecal Coliforms
RES Residual
NR No Results
Cl Chlorine
Conc Initial concentration

Table 8. (continued) DISINFECTION RESULTS

Surv TC (3)	Surv FC (3)	O_3 Conc. (mg/l)	pH	Det. time (min)	Surv TC (3)	Surv FC (3)
420	<100	NR	NR	NR	NR	NR
<100	< 10	8.4	7.0	3.3	2600	50
100	< 10	8.4	7.4	3.3	120	60
20	< 10	8.4	7.2	3.3	480	30
160	< 10	NR	NR	NR	NR	NR
18000	20	NR	NR	NR	NR	NR
< 10	< 10	NR	NR	NR	NR	NR
20	< 10	NR	NR	NR	NR	NR
5200	480	7.2	7.4	3.3	40	< 10
> 80000	1300	7.2	7.1	3.3	< 10	10
4600	120	7.2	7.2	3.3	< 10	10
NR	< 10	3.8	NR	3.3	15000	< 10
2000	< 10	NR	NR	NR	NR	NR
7000	80	3.1	NR	3.3	12000	2850
170	< 10	NR	NR	NR	NR	NR
7000	< 10	3.1	NR	3.3	6100	250

chlorine concentrations; however, in one instance when 5 mg/l chlorine was added, the resulting surviving total and fecal coliforms were above the acceptable limit. The results indicate that with the proper chlorine concentration adequate disinfection can be achieved in very short contact times in a high velocity gradient chlorine contact chamber.

Disinfection results for the microstrained effluent using ozone in a cocurrent column were obtained for seven storms and are listed in Table 8. The ozone contact column had a contact time of 3.3 minutes and the concentrations were varied from 3.1 mg/l to 8.4 mg/l. The results show that total and fecal coliform levels of less than 200 FC/ 100 ml and 1000 TC/100 ml could be achieved at the higher concentrations of 7-9 mg/l. Ozone would probably not be as suitable as chlorine for this application because of the somewhat higher capital and operating costs for O_3 vs Cl_2. However, the use of ozone should not be overlooked since the cost gap for chlorine vs ozone is already closing. The concentrations necessary to meet disinfection requirements are higher for ozone than for chlorine because ozone is a more powerful oxidant and reacts more vigorously with the organics. For this reason ozone has many advantages over chlorine such as the destruction of phenols whereas when chlorine is used, the obnoxious chlorophenols are formed; ozone is more effective in the reduction of color and odor; ozone is a much better viricide; and also by the method of application using air, an increased dissolved oxygen content is imparted to the treated water.

SECTION VII
ECONOMICS

The economics of Microstraining of combined sewer overflow followed by high rate disinfection using chlorine was based on a drainage area of 2.3 hectares (5.7 acres). The facility would receive 8.2 cu m/min/hectare (1.96 cfs/acre) which was equivalent to 28000 cu m/day (7.4 mgd). The costs are based on treatment of 1.5×10^6 cu m/yr (3.85×10^8 gal/yr) of storm flow.

The costs are based on treatment with and without polyelectrolyte. With polyelectrolyte addition, two, 1.5 m (5 ft) by 1.5 m (5 ft) microstrainers are employed, rated at 97 m/hr (40 gpm/sq ft). When no polyelectrolyte is used, four microstrainers are necessary since they are rated at one-half the capacity, 48.5 m/hr (20 gpm/sq ft). All costs are in 1973 dollars.

	Polyelectrolyte Addition	No Polyelectrolyte Addition
Capital Costs		
Material and Equipment		
Microstrainer	$42000.	$84000.
Pumps & controls	$ 4800.	$ 9600.
Building	$ 4100.	$ 8200.
Grating & railing	$ 1345.	$ 2690.
Chamber	$ 7985.	$15970.
Bar Screen	$ 1700.	$ 1700.
Chlorine Equipment	$ 1440.	$ 1440.
Chamber	$ 5870.	$ 5870.
Building & grating	$ 1440.	$ 1440.
Polyelectrolyte equipment (inc. tank,pump, mixer, and controls)	$ 6000.	$ 0
Mixing chamber	$ 4000.	$ 0
Installation	$ 5000.	$ 8600.
Total Capital Cost	$85680.	$139510.

	Polyelectrolyte Addition	No Polyelectrolyte Addition
Annual Operating Costs		
Capital charge @ 10% installed facility (less land and engineering)	$ 8568.	$13951.
Utilities	$ 300.	$ 600.
Maintenance and supplies @1% of installed facility cost	$ 857.	$ 1395.
Chlorine cost @$0.10/lb. Cl_2 gas @ 6 mg/l	$ 1900.	$ 1900.
Polyelectrolyte cost @$1.77/lb for 1 mg/l	$ 5600.	0
Total Operating Cost	$17225.	$17846.
Summary		
Capital Costs		
$/hectare	37250	60660
$/acre	15030	24480
$/mgd	11580	18850
Operating Costs		
$/hectare yr	7490	7760
$/acre yr	3020	3130
$/1000 gal	0.045	0.046

SECTION VIII

OPERATION AND MAINTENANCE OF THE MICROSTRAINER

During Phase III, the microstrainer operated continuously with very few maintenance problems. For the entire 10 month period, there was only one breakdown which was caused by a broken v-belt located between the electric motor and the gear drive. The only other problems encounterd were due to air leaks in the differential control system due to badly worn copper tubing, an occasional fouled screen, clogged backwash nozzles and the replacement of the sealing bands which hadn't been replaced for three years.

It should be pointed out that the microstrainer was operated at a liquid differential of 24 inches and this was only permissable because of the intermittent (storm) load conditions. After three years of intermittent operation at the Philadelphia pilot site all screen fabric remained in good condition as determined by microscopic examination. The normal (dry-weather treatment) recommended differential for continuous operation is 6 inches. The microstrainer fabric will last indefinitely under a 6 inch differential depending on the particular application.

A full scale microstrainer facility for operation during storm conditions would be housed and kept from freezing in an insulated building. The facility would be automated. At the onset of storm overflow the liquid level in the inlet channel rises and actuates a level switch which starts the microstrainer drum motor, the backwash jets, the bar screen rake drive and turns on the UV lights. The microstrainer unit would be automatically controlled by pneumatic measurements of the differential head across the screen which would be transmitted to a convertor mechanism. This would control the drum speed and would allow for variations in solids concentrations and flow while maintaining a constant differential of 24 inches.

After a storm, the program controls continue the operation of the microstrainer, sump pumps and backwash pump until

the chamber is drained and the screen is cleaned and then shuts them down. Because of the ease of start-up and the very low residence volume of the microstrainer, unattended operation can be accomplished with very simple controls.

The inlet chamber would be constructed with relief weirs to enable bypassing excessive flows and the floor would be sloped and valved for desludging and draining.

Although during the Phase III pilot study the microstrainer ran continuously under an ultraviolet light and constant backwash, under actual conditions the equipment would stand idle during dry periods. To keep the microstrainer fabric in condition to operate when needed, it must not be allowed to remain full of raw sewage while not operating. The settled solids foul the bottom of the screen and the dry top portion may become too hardened and may be difficult to backwash clean. The recommended procedure for combined sewer overflow service is to drain the chamber, continue the backwash of the slowly rotating drum using city water as washwater for 15-30 minutes and then stop the drum and backwash water. For sustained dry periods the drum can be rotated slowly for short periods at intervals under backwash jets and the UV lights.

It is imperative that the microstrainer fabric be kept clean. The backwash nozzles should be checked and cleaned when necessary. If the raw combined sewer overflow is high in manganese and iron, after a long period their respective oxides may eventually build up and foul the screen. Screen cleaning can be accomplished by turning off the backwash jets and while allowing the drum to rotate slowly, a few gallons of cleaning solution are sprinkled over the fouled screen. The drum is then rotated for about 10 minutes in this solution and then a high pressure backwash is applied. The tank is then drained and the unit is ready for operation.

Some of the cleaning solutions used are: sodium hypochlorite for organic fouling (chlorine gas should never be used), Jenolite solution (based on phosphoric acid) for the removal of iron and manganese oxides, and hydrogen peroxide for hardened clay-like materials.

In general, the microstrainer is an effective and economical method of treatment. It can be operated with very little maintenance, other than the normal lubrication and maintenance associated with mechanical equipment. Running costs are low, consisting mainly of the electricity required for driving the motor, backwash pump and debris water pump.

SECTION IX

REFERENCES

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SECTION X

PUBLICATIONS

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10. Diaper, E.W.J. "Combined Sewer Overflows", presented at Technology Transfer Seminar sponsored by the E.P.A., Newark, N.J.,(March 1974).

SECTION XI

APPENDICES

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APPENDIX A

COAGULATION STUDY

Membrane Refiltration Test

Date	Coagulant type	Initial conc. (mg/l)	Filter tube vol(ml)/ 9 sec.	Millipore time (min)/ 100 ml
7/13/73	200 mesh coal	50	335	7.6
			280	7.5
	100 mesh coal	50	400	4.3
			370	6.3
7/16/73	straight	0	270	14.3
			255	13.9
			255	
7/16/73	200 mesh coal	50	240	16.2
			232	17.5
			230	
7/16/73	100 mesh coal	50	230	16.1
			242	15.1
			230	
7/16/73	Dow C-31,	4	228	15.0
	200 mesh coal	50	240	15.0
			204	
7/16/73	Dow C-31	4	269	10.5
	100 mesh coal	50	283	10.2
			255	
7/16/73	Dow N-11,	4	204	22.3
	200 mesh coal	50	210	18.7
7/16/73	Dow N-11	4	242	7.2
	100 mesh coal	50	248	11.8
			244	
7/16/73	Atlasep 2A2	4	186	30.9
	200 mesh coal	50	190	24.1
			174	
7/16/73	Atlasep 2A2	4	200	16.8
	100 mesh coal	50	198	17.3
			198	

APPENDIX A

COAGULATION STUDY

Membrane Refiltration Test

Date	Coagulant type	Initial conc. (mg/l)	Filter tube vol(ml)/ sec.	Millipore time (min)/ 100 ml
8/3/73	straight	0	185	19.2
			182	20.0
8/3/73	alum	10	144	16.1
			140	16.8
			138	
8/3/73	Atlasep 2A2	4	80	61.1
			74	69.1
			70	
8/3/73	100 mesh coal	50	126	15.1
			120	19.2
			114	
8/3/73	alum,	10	60	60.0
	Atlasep 2A2	4	30	49.5
			42	
8/3/73	alum,	10	40	54.6
	Atlasep 2A2	4	50	53.5
	100 mesh coal	50	50	
8/3/73	Atlasep 2A2	4	68	25.6
	100 mesh coal	50	74	24.2
			74	
8/3/73	alum,	10	78	33.3
	100 mesh coal	50	72	33.3
			70	
8/17/73	straight	0	110	32.1
			105	35.5
			115	
8/17/73	$FeCl_3$	10	80	23.7
			73	21.5
			78	

APPENDIX A

COAGULATION STUDY

Membrane Refiltration Test

Date	Coagulant type	Initial conc. (mg/l)	Filter tube vol(ml)/ 9 sec.	Millipore time (min)/ 100 ml
8/17/73	Atlasep 2A2	4	30	89.3
			20	
			21	
8/17/73	100 mesh coal	50	22	32.7
			85	
			92	
8/17/73	$FeCl_3$,	10	14	44.7
	Atlasep 2A2	4	10	
			13	
8/17/73	$FeCl_3$,	10	18	39.1
	Atlasep 2A2 ,	4	15	48.5
	100 mesh coal	50	13	
8/17/73	Atlasep 2A2,	4	20	90+
	100 mesh coal	50	18	
			18	
8/17/73	$FeCl_3$,	10	26	12.0
	100 mesh coal	50	28	13.1
			25	
8/17/73	Dow C-31	4	59	5.3
			54	5.3
			56	
8/17/73	Dow C-31,	4	50	5.3
	100 mesh coal	50	52	6.0
			49	
8/24/73	straight	0	57	16.5
			60	
			59	
8/24/73	100 mesh coal	50	65	19.0
			59	
			64	

APPENDIX A

COAGULATION STUDY

Membrane Refiltration Test

Date	Coagulant type	Initial conc. (mg/l)	Filter tube vol(ml)/ 9 sec.	Millipore time (min)/ 100 ml
8/24/73	Lime	10	64	24.5
			60	
			70	
8/24/73	Dow C-31	4	60	9.0
			58	
			58	
8/24/73	Atlasep 2A2	4	37	90+
			25	
			22	
8/24/73	Lime,	10	43	39.7
	Dow C-31	4	57	
			57	
8/24/73	Lime,	10	40	90+
	Atlasep 2A2	4	29	
			24	
8/24/73	Lime,	10	60	50.5
	100 mesh coal	50	65	
			65	
8/24/73	Dow C-31,	4	68	9.5
	100 mesh coal	50	64	
			67	
8/24/73	Atlasep 2A2,	4	45	90+
	100 mesh coal		29	
			23	
8/24/73	Dow C-31,	4	64	36.0
	Lime,	10	61	
	100 mesh coal	50	62	
8/24/73	Atlasep 2A2,	4	46	90+
	Lime,	10	41	
	100 mesh coal	50	38	

APPENDIX A

COAGULATION STUDY

COAGULATION JAR TEST

Temperature = 22.5°C

30 second fast mix at 150 rpm followed by 60 second slow mix at 10 rpm

Date	Coagulant type	Initial conc. (mg/l)	Remarks
9/21/73	Atlasep 105C	0.5	Medium sized floc
		1.0	Large, ball-like floc
		1.5	Large, ball-like floc
		2.0	Overdosed, stuck to paddle
		2.5	Overdosed, stuck to paddle
9/21/73	Dow Purifloc C-31	0.5	No floc formation
		1.0	No floc formation
		1.5	No floc formation
		2.0	No floc formation
		2.5	No floc formation
		3.0	Very small, slow settling
		4.0	Very small, slow settling
9/21/73	Betz 1190	0.5	No floc formation
		1.0	No floc formation
		1.5	No floc formation
		2.0	No floc formation
		2.5	No floc formation
		5.5	Small floc
		11.0	Small floc
		16.5	Small floc
		22.0	Small floc
		27.5	Small floc
9/21/73	Betz 1160	0.5	Small floc
		1.0	Fair floc
		1.5	Large floc
		2.0	Large floc
		2.5	Large floc

APPENDIX A

COAGULATION STUDY

Date	Coagulant type	Initial conc. (mg/l)	Remarks
9/24/73	Betz 1150	0.5	No floc formation
		1.0	No floc formation
		1.5	Fair floc
		2.0	Large floc
		2.5	Large floc
9/24/73	Betz 1170	5.0	No floc formation
		10.0	No floc formation
		15.0	No floc formation
		20.0	No floc formation
		25.0	No floc formation
9/24/73	Betz DK-522	2.5	Very small floc,no settling
		5.0	Very small floc,no settling
		7.5	Very small floc,no settling
		10.0	Very small floc,no settling
		12.5	Very small floc,no settling
9/24/73	Betz 1190	10.0	Very small floc,no settling
		15.0	Very small floc,no settling
		20.0	Very small floc,no settling
		25.0	Very small floc,no settling
		30.0	Very small floc,no settling
9/24/73	Betz 1175	5.0	Medium floc, slow settling
		10.0	Medium floc, slow settling
		15.0	Medium floc, rapid settling
		20.0	Medium floc, rapid settling
		25.0	Medium floc, rapid settling
9/27/73	Betz 1110	0.5	No floc formation
		1.0	No floc formation
		1.5	No floc formation
		2.0	No floc formation

APPENDIX A

COAGULATION STUDY

Date	Coagulant type	Initial conc. (mg/l)	Remarks
9/24/73	Atlasep 2A2	0.5	No floc formation
		1.0	No floc formation
		1.5	No floc formation
		2.0	No floc formation
		2.5	No floc formation
9/24/73	Atlasep 4A4	0.5	No floc formation
		1.0	No floc formation
		1.5	No floc formation
		2.0	No floc formation

Membrane Refiltration Test

Date	Coagulant type	Initial conc (mg/l)	Filter tube vol/9 sec (ml)	Millipore time (min)/ 100 ml
9/25/73	straight	0	140	4.3
	Atlasep 105C	1.0	350	30+
		1.5	380	30+
9/25/73	Betz 1150	2.5	351	30+
		3.0	505	30+
9/25/73	Betz 1160	3.0	145	2.2
		3.5	214	5.8
9/25/73	Betz 1175	15.0	136	30.5
		20.0	140	24.8
9/25/73	Dow C-31	4.0	205	21.7
		4.5	191	15.4

APPENDIX B

TABLE OF CONVERSIONS

Metric Unit	Multiplier	English Unit
hectare	2.47	acre
m	3.28	ft
cm	2.54	in
cu m	264.20	gal
sq m	10.76	sq ft
cu m/hr	0.00026	mgd
m/hr	0.408	gpm/sq ft

APPENDIX C

DISINFECTION PERCENT REMOVALS

Raw Combined Sewer Overflow

Date	Initial Cl_2 conc. (mg/l)	Contact time (min)	Initial TC(1)	%Removal	Initial FC(2)	%Removal
6/22/73	5.0	4.25	41.0	99.963	2.0	99.450
6/29/73	12.0	4.25	16.0	99.969	1.4	99.929
6/29/73	12.0	4.25	18.0	99.994	0.71	99.859
	12.0	4.25	18.0	99.987	0.71	99.859
	12.0	1.25	18.0	99.992	0.71	99.859
7/11/73	5.0	4.25	8.9	84.944	15.0	96.000
7/15/73	9.0	4.25	6.2	90.323	0.5	Inc.
	9.0	4.25	6.2	90.968	0.5	98.000
8/1/73	5.1	4.25	45.0	99.999	3.2	99.969
8/2/73	5.1	4.25	26.0	98.846	1.8	66.667
	5.1	4.25	26.0	99.742	1.8	98.888

Microstrained Combined Sewer Overflow

Date	Initial Cl_2 conc. (mg/l)	Contact time (min)	Initial TC(1)	%Removal	Initial FC(2)	%Removal
6/22/73	5.0	4.25	13.0	99.968	0.27	96.269
6/29/73	5.0	4.25	5.9	99.983	0.74	99.865
6/29/73	5.0	4.25	64.0	99.998	5.1	99.980
	5.0	4.25	64.0	99.999	5.1	99.980
	5.0	1.25	64.0	99.998	5.1	99.980

APPENDIX C

DISINFECTION PERCENT REMOVALS

Microstrained Combined Sewer Overflow

Date	Initial Cl_2 conc. (mg/l)	Contact time (min)	Initial TC(1)	%Removal	Initial FC(2)	%Removal
7/11/73	5.0	4.25	1.4	87.143	0.15	98.667
7/15/73	5.0	4.25	6.0	99.998	0.6	99.833
	5.0	4.25	6.0	99.998	0.6	99.833
8/1/73	5.6	4.25	5.0	98.960	0.7	93.143
8/2/73	5.6	4.25	15.0	94.667	0.7	81.429
	5.6	4.25	15.0	99.693	0.7	98.286
12/20/73	2.7	1.25	4.0	98.250	8.0	99.988

Date	Initial O_3 conc. (mg/l)	Contact time (min)	Initial TC(1)	%Removal	Initial FC(2)	%Removal
6/29/73	8.4	3.3	5.9	99.559	0.74	99.324
6/29/73	8.4	3.3	64.0	99.998	5.1	99.882
	8.4	3.3	64.0	99.992	5.1	99.941
8/1/73	7.2	3.3	5.0	99.992	0.7	99.857
8/2/73	7.2	3.3	15.0	99.999	0.7	99.857
	7.2	3.3	15.0	99.999	0.7	99.857
12/20/73	3.1	3.3	4.0	98.475	8.0	99.688

(1) Cells/100 ml x 10^5

(2) Cells/100 ml x 10^4

TC Total coliforms

FC Fecal coliforms

Cl_2 Chlorine

O_3 Ozone